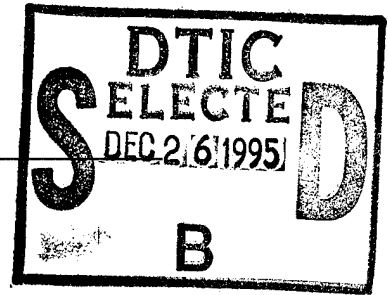AD_____

GRANT NO: DAMD17-94-J-4318

TITLE: Evaluation of a Digital Telemammography System: A Model for a Regional System

PRINCIPAL INVESTIGATOR(S): Ellen Shaw de Paredes

CONTRACTING ORGANIZATION: University of Virginia
Charlottesville, Virginia 22906

REPORT DATE: October 1995

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release;
distribution unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

19951220 054

DTIC QUALITY INSPECTED 3

DISCLAIMER NOTICE

UNCLASSIFIED

Technical Report
distributed by

DEFENSE
TECHNICAL
INFORMATION
CENTER

DTIC Acquiring Information-
Imparting Knowledge

Cameron Station
Alexandria, Virginia 22304-6145

UNCLASSIFIED

THIS DOCUMENT IS BEST
QUALITY AVAILABLE. THE
COPY FURNISHED TO DTIC
CONTAINED A SIGNIFICANT
NUMBER OF PAGES WHICH DO
NOT REPRODUCE LEGIBLY.

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1995	Annual 16 Sep 94 - 15 Sep 95

4. TITLE AND SUBTITLE
Evaluation of a Digital Telemammography System: A Model for a Regional System

5. FUNDING NUMBERS
DAMD17-94-J-4318

6. AUTHOR(S)
Ellen Shaw de Paredes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Virginia
Charlottesville, Virginia 22906

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The research hypothesis being tested is that a telemammography system utilizing a laser film digitizer at the transmitting site (with a 50-micron pixel size for spatial resolution and a 12-bit pixel range for contrast) and interactive two grayscale display monitors (2048 x 2560 x 8/12 bits) at the receiving site can be used to interpret mammography images with an accuracy level sufficient for primary diagnosis. To test the research hypothesis, the following four aims are to be completed: (1) Collection of 200 normal cases and 200 abnormal cases of specifically selected analog mammographic film images and patient data for use in evaluating a telemammography system; (2) convert the collected database of analog mammographic films into digital arrays using a laser film digitizer with a 50-micron pixel spot size and 12 bits per pixel of dynamic range; (3) conduct an ROC analysis of the retrospective database of the analog mammographic image and digitized arrays displayed on the two monitor interactive gray scale workstation, each monitor displaying 2048 x 2560 x 8/12 bit portions of the 4K x 4K digitals arrays; (4) implement a digital transmission for evaluation of the telemammography system; (5) implement and test a quality control program; and (6) evaluate the throughput rate of the implemented telemammography system.

DTIC QUALITY INSPECTED 3

14. SUBJECT TERMS			15. NUMBER OF PAGES
FBDI (Full Breast Digital Image), DS-0, T1, DS-1 breast cancer			141
			16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements*.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	-	Contract	PR -	Project
G	-	Grant	TA -	Task
PE	-	Program Element	WU -	Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the US Army.

_____ Where copyrighted material is quoted, permission has been obtained to use such material.

_____ Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

_✓_ Citations of commercial organizations and trade names in this report do not constitute an official Department of Army endorsement or approval of the products or services of these organizations.

_____ In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Resources, National Research Council (NIH Publication No. 86-23, Revised 1985).

_✓_ For the protection of human subjects, the investigator(s) adhered to policies of applicable Federal Law 45 CFR 46.

_____ In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institutes of Health.

_____ In the conduct of research utilizing recombinant DNA, the investigator(s) adhered to the NIH Guidelines for Research Involving Recombinant DNA Molecules.

_____ In the conduct of research involving hazardous organisms, the investigator(s) adhered to the CDC-NIH Guide for Biosafety in Microbiological and Biomedical Laboratories.

PI – Signature   10/9/95   Date

Accession For

NTIS GRA&I	✓
DTIC TAB	☐
Unannounced	☐
Justification	

By_____
Distribution/
Availability Codes

| Dist | Avail and/or Special |

A-1

Table of Contents

INTRODUCTION

1.1 Nature of the Problem

Routine mammograms are an essential element of health care for adult women (1-5). Digital technology promises improved lesion detection and, in conjunction with teleradiology, improved access to mammography compared to current conventional techniques (6,7). However, because mammography requires high spatial resolution over a large area, good contrast resolution over a large dynamic range, and high detective efficiency for x-rays, the development of full-breast digital imaging (FBDI) technology has been slow (reviewed in 8). While FBDI technology will be implemented over the next three to five years, the current screen film mammography examinations will remain the standard for use in teleradiology systems. Digital imaging methods will ultimately replace analog (screen-film) systems; filmless systems will become an integral part of local-area and wide-area networks and digital x-ray mammography units will eventually reach the market. These modalities generate large volumes of digital data and thus will require an efficient communications interface if the data are to be managed in reasonable time frames. Furthermore, a standard interface must be implemented lest the telemammography benefits envisioned for the near future disappear into a costly and inefficient world of incompatible systems. We believe it is essential now, during the prototype stage of system development, to implement and evaluate an interface that satisfies the Digital Imaging and Communications in Medicine (DICOM 3.0) standard (9-13).

To make transmission and archival of digital image files practically feasible, image compression algorithms (14-16) are necessary as a means of compacting and reducing the enormous data sets generated by a digital full-breast mammogram (4K x 4K x 2 Bytes = 32 MB/image x 4 images/screening exam, or 8 images for comparing past and present exams). Using software (AWARE), Inc, Waltham, MA) for wavelet compression (17-23), we have studied wavelet transforms of digitized screen-film mammograms at compression ratios of 50:1 to 100:1; and have determined from a contrast-detail phantom study that 50:1 is an acceptable ratio. Wavelet transforms are multiresolution decomposition tools, with the kernel of wavelet transform obtained by dilation and translation of a selected bandpass filter. Compression for digitally acquired images will demand new filter designs to attenuate the effects from the high detective quantum efficiency and low noise of digital detectors without distorting mammographic features.

The use of T1 digital transmission service (1.544 Mbits/sec signaling speed) is expensive for use in telemammography. An estimate of T1 costs is $19/month/mile per site and access charges of approximately $1,000 per month. The use of a successful compression ratio of 24 to 1 enables a DS-O digital service (64K bits/sec) to accomplish the same signaling rate of a DS-1 (equivalent to T1 service) channel.

Digital display technologies are limited, for the near future, to 8/12 bit pixel laser film printers and 2K x 2.5K interactive

4

high-resolution gray-scale monitors. We have extensive experience with both of these display modalities. Like other components of the digital mammography system, the display modalities face special challenges as a result of the amount of data generated by digitally acquired examinations. The critical effort with the laser film printer is the development of appropriate look-up tables (24-27), so that the digital detector output, which is a 4K x 4K digital array with 63-micron pixel size and 12 bits/pixel of dynamic range, is optimally transferred at 8/bits per pixel to the laser-imaged films. In the case of the gray-scale displays, the problems are more complex (28-34). To be usefully implemented, there are four standard mammographic (screening) views that must be displayed (craniocaudal (CC) and mediolateral oblique (MLO) views of each breast) at a two-monitor workstation; in some cases, at least two diagnostic views (spot compression or magnification)(performed in two different projections (usually 90° apart) will also be viewed, as will both the current and the previous examination. A mammographer using a gray-scale monitor will need rapid displays with easily used interactive commands. In addition, the system must effectively display the 4K x 4K image matrix on a 2K x 2.5K screen. A well-designed display protocol meeting all these needs could become a standard implemented by a digital signal processing (DSP) board or an accelerator board. Such a standard would enable faster throughputs for the mammographer and aid in the establishment of quality control standards for visualizing digital mammography examinations.

1.2 Purpose of the Present Work

The research hypothesis being tested is that a telemammography system can interpret mammography images with an accuracy level sufficient for primary diagnosis utilizing a film digitizer at the transmitting site (with a 50-micron pixel size for spatial resolution and 12 bit pixel range for contrast) and interactive grayscale display monitors (2048 x 2560 x 8/12 bits) at the receiving site.

A successful telemammography system will provide benefits in the following four areas:

A.   PRIMARY DIAGNOSIS. Telemammography offers the ability to provide mammographic consultations to underserved and remote areas. Achieving the image quality required of a telemammography system for primary diagnosis will enable an outreach program to enhance a region's breast screening programs and to improve patient care.

B.   INTEGRATION OF MAMMOGRAPHY GROUP PRACTICE DISTRIBUTED OVER MULTIPLE IMAGING CENTERS. As the awareness regarding the role of mammography in early detection of breast cancer increases, so does the need for accessibility to low cost screening mammography. More and more practices are responding to the rapidly growing utilization of mammography by opening satellites to imaging practices. Telemammography would enable a group with a limited number of expert mammographers to handle multiple off-site practices. Additionally, if

appropriate for the practice, the radiologist could supervise screening mammograms off-site and determine the need for any additional views at the time of the examination instead of having the patient return at a later time. Image quality could also be supervised off-site via telemammography. Another advantage of this system is that, due to efficiencies of scale, mammography costs would be lower and a lower fee for interpretation could be maintained without the need for an on-site radiologist. In part, this would be related to alleviating the need for the physician to travel to and from various satellite screening sites.

C. OVERREADING OF MAMMOGRAPHY IMAGES. There is increasing emphasis on the interpretive skills of radiologist's reading mammograms as part of the quality assurance process monitored both by the ACR Mammography Accreditation program and by the Food & Drug Administration. Residency programs are offering more time in mammography rotations now compared with only a few years ago; there have been formal standardized training programs for radiology residents and mammographic technologists through the ACR-CDC Cooperative Agreement. Nonetheless, the impact of the accreditation guidelines and the training programs will not be immediate, and there remains a need for expert mammographic interpretation in many practices. With

7

telemammography, a small number of expert mammographers could provide consultation services or second readings of mammograms for a larger number of general radiologists, and improve the quality of care. Additionally, the data and images for patients in a region could be stored and utilized for the development of a regional mammography database.

D. IMPROVED CONSULTATION WITH SURGEON AND PCP. Primary care physicians and surgeons could review the mammograms on their patients without the need for "signing out" the original films, thus providing more reliable continuing service and decreasing the risk of loss of films. On a broader scale, the utilization of telemammography at multiple radiology practices in a referral region could provide greatly improved access to a patient's prior examination, regardless of where the patient obtained subsequent mammograms. The importance of such transmission would be multifocal: original films would not need to be mailed, risking their loss, the cost of making copy films could be avoided: and the facility interpreting the current study would have a much more rapid access to the prior exams, thereby, improving the accuracy of diagnosis and diminishing the anxiety of the patient who is waiting for her final results.

1.3 Methods of Approach

Three tasks are required in support of evaluating the research hypothesis.

Task 1. A selected set of analog mammographic films will be collected and digitized using a laser film digitizer set at a 50-micron spot size and a 12-bits dynamic range. An ROC analysis will be conducted on the analog mammographic films and the digitized films displayed on grayscale monitors (2048 x 2560 x 8/12 bits).

Task 2. A digital communication network will be implemented between the Department of Radiology Breast Imaging Center in the Diagnostic Center for Women (primary Care Center Building, UVa) and the off-campus outpatient Virginia Mammography Center (Northridge facility, UVa, 8 miles from the campus). A laser film digitizer (50-micron spot size, Model 150, Lumisys Inc, Sunnyvale, CA) and computer workstation (SUN, SPARC Model 40) will be installed at the Northridge. Transmission of the digitized mammographic films will be over a T-1 carrier (1.544 Mbits/sec signaling speed) to the department's PACS and displayed on 2048 x 2560 x 8/12-bit grayscale monitors. A protocol for end-to-end telemammographic quality control will be implemented.

Task 3 A performance evaluation will be conducted of the teleradiology system using the metrics of <u>response time, throughput, reliability, and clinical acceptance.</u>

We divided the above three tasks into the following aims:

Aim 1. Collection of an adequate retrospective database of

analog mammographic film images and patient data for use in evaluating a telemammography system.

<u>Aim 2.</u> Convert the collected database of analog mammographic films into digital arrays using a laser film digitizer with a 50 micron pixel spot size and 12 bits per pixel of dynamic range.

<u>Aim 3.</u> Conduct an ROC analysis of the retrospective database of the analog mammographic images and the digitized arrays displayed on the 2048 x 2560 x 8/12-bit grayscale monitors.

<u>Aim 4.</u> Implement a digital transmission service between the Virginia Mammography Center at Northridge and the PACS in the University of Virginia Department of Radiology and its workstations including that in Diagnostic Center for Women.

<u>Aim 5.</u> Design, implement, and evaluate an end-to-end quality control program for the telemammography system.

<u>Aim 6.</u> A performance evaluation will be conducted of the telemammography system using the metrics of <u>response time, throughput, reliability, and clinical acceptance.</u>

2. Experimental Methods and Results

2.1 Statement of Work.

The proposed statement of work for the contract was identified by the year and aim as follows. We present these Tasks and Aims, commenting on our current progress at the completion of the first year of the contract (in script font).

<u>YEAR 1</u>

TASK 1: Aim 1

10

*   Complete collection of 200 normal and 200 biopsy-proven
     malignant analog mammographic films to form an image
     database (6 months to complete).

*   Collect pathology and consultation reports for
     the 400 images in the database.

*   Conduct an image quality control protocol on
     the image database to insure correct ground
     truth identification, correct diagnosis, and
     an adequate optical density range in each
     image.

*   Conduct a review of the identified Regions of
     Interest (ROIs) to insure proper identificati
     on.

*We have completed the collection of 200 normal and 200
abnormal analog mammographic films to form our image data base (see
Appendix I for a listing (coded by case number). (Abnormal cases
include benign and malignant lesions, with pathology serving as
gound truth.) We have completed the collection of patient data and
will be adding the patient's age as well as demographic data. We
conducted an image quality control protocol on the analog image
database to insure correct ground truth identification, correct
diagnosis, and the proper optical density range in each image. All
cases were reviewed and lesions were analyzed and classified using
ACR lexicon. The abnormal cases were also verified for presence of
only one lesion. The abnormals selected reflected a range of*

difficulty in lesion perception and analysis.

Normals were selected as normal based on the following: (1) Initial consultation reading was normal; (2) review of images showed no significant abnormality; and (3) follow-up mammogram at least 24 months later showed no interval change. Mammographic findings of intramammory lymph nodes, calcification of fat necrosis, dermal calcifications and vascular calcification are considered pathognomically benign and could be present on "normal" cases.

Parenchymal density for each case was classified on a scale of 1 to 4. (1 = fatty; 2 = scattered fibroglandular tissue; 3 = heterogenously dense; and 4 = extremely dense). The density of normal cases was matched to abnormals. There were an approximately equal number of fatty normals, fatty abnormals, etc.

The image database was initially collected together with an overlay sheet of clear plastic identifying the Regions of Interest (ROIs) to insure proper identification. Our intent was to digitize this RBI and use it for display on the grayscale workstations. We have discontinued this portion of the project as it introduces a bias in the reader response. That is, if only a 1K x 1K ROI is displayed to each reader, a bias is introduced by not displaying the full image.

YEAR 1.

    TASK 1: Aim 2

    *   Begin digitization of analog mammographic films (requires eight months to complete,

starting in last six months of Year 1 and two months of Year 2).

* Digitize the 400 analog mammographic images with a 50 micron pixel spot size and 12 bits per pixel of dynamic range.

* Conduct a review of the digitized images using the grayscale display workstations (2048 x 2560 x 8/12 bits) in the PACS network.

* Archive the 400 digitized mammographic arrays and the patient data in a relational database (Sybase) on the PACS network.

* Digitize the 400 mammographic images with a 23-micron spot size film digitizer (DBA, Fairfax, Virginia) and evaluate any significant difference between the 50-micron and 23-micron spot size digital arrays by the following: (a) registering and subtracting the RBI region, multiplying the difference image by 10, and calculating the mean square error; (b) displaying on the grayscale display stations the two digital arrays (50 micron and 23 micron) and inspecting the displayed images to detect any significant differences (each display station has two monitors).

We have completed digitizing 350 of the 400 mammography cases. These have been digitized using a 50 micron spot size and archived

onto 8 millimeter DAC tape. These digital array images have been interactively cropped using a rectangular window in order to minimize the background of the digital image.

We have encountered two problems in accomplishing Task 1, Aim 2 of the first year. _First_, the software operating on our 16 two-monitor grayscale workstation was modified by EMED (E-Systems, EMED, San Antonio, TX) when changing our PACS from DOS to a UNIX operating system. Laser Film Digitized Images lacked the expected DICOM header block. It took two of our graduate students four months to discover this problem. Through the efforts of our graduate students, we are now able to load laser film digitization mammography films (4K x 4K) into our PACS and display them on the 2K x 2.5K grayscale workstations.

Second, our arrangement with DBA (Fairfax, Virginia) to digitize the 400 mammographic images at a 23-micron spot size (CCD detector) is not currently possible for the following reasons: (1) DBA expects for us to pay $5,000 a month (plus a maintenance charge of $800/month) to install their CCD film digitizer (we can not afford to do this); (2) the DBA CCD film digitizer that we had discussed is limited to 8 bits of dynamic range; (3) the use of 50 micron spot size on the laser film digitizer matches the sampling frequency required for analog film-screen mammography images when scatter is considered (scatter limits the radiographic information to a spatial resolution of approximately 7 lines per millimeter); and (4) the radiographic magnification of approximately 2.3 to 2.4 enables a spot size of 50 microns to be equivalent, in the actual

image size, to approximately 45 microns. We are currently conducting a study using 23 m spot size with a set of mammography cases (10 normal and 10 abnormal) to determine a measure of the image quality, using mean-square-values, to determine differences between 50 micron and 23 micron spot sizes.

TASK 1: Aim 3

*   Begin initial ROC curve analysis of mammographic analog films (8 months to complete, final 6 months of Year 1 and two months of Year 2) by six readers.

We have completed the initial ROC analysis of the readers. We have expanded the number of readers from six to eleven. Image grading is conducted with the following gradings.

Masses 1 (definitely not present); 2 (probably not present); 3 (equivocal); 4 (Probably present); 5 (definitely present).

Microcalcifications 1 (definitely not present); 2 (probably not present); 3 (equivocal); 4 (probably present); 5 (definitely present).

Dilated lactiferous ducts 1; 2; 3; 4; 5.

Focal areas of asymmetry or architectural distortion 1; 2; 3; 4; 5.

Diagnosis of image 1 (definitely benign); 2 (probably benign); 3 (equivocal); 4 (probably malignant); 5

15

(definitely malignant).

Our initial ROC results are detailed in Appendix

For year 2 the following Tasks and Aims are to be accomplished.

YEAR 2

TASK 1: Aim 2

*   Complete digitization of the collection of the analog mammographic films (two months of Year 2, began in Year 1).

TASK 1: Aim 3

*   Complete ROC analysis of mammographic analog films (requires two months of Year 2 to complete task began in the first year).

TASK 1: Aim 3

*   Utilize the collected digitized image data set to perform an ROC curve analysis (requires six months) utilizing the 2048 x 2560 x 8/12 bit grayscale display stations in the University of Virginia PACS by six readers.

TASK 2: Aim 4

* Implement the T-1 connection between Northridge facility and the University of Virginia PACS (three months of Year 2).

* Test network for end-to-end fidelity.

TASK 2: Aim 5

* Design, establish, and test an end-to-end quality control program for validating a telemammography system.

* Operate the telemammography system to collect data for evaluating the quality control program.

For Years 3 and 4 the following Tasks and Aims are to be accomplished.

YEAR 3

TASK 1: Aim 3

* Complete the ROC analysis of digitized mammographic images displayed on 2048 x 2560 x 8/12 bit grayscale display stations in the University of Virginia PACS.

TASK 2: Aim 5

* Implement the end-to-end quality control program for evaluation and analysis.

TASK 3: Aim 6

* Implement a software data logger program which will record events on the telemammography system.

* Implement the performance evaluation using the metrics of <u>response time, throughput, reliability, and clinical acceptance.</u>

<u>YEAR 4</u>

TASK 2: Aim 5

* Evaluate the end-to-end image quality control protocol for the teleradiology system.

TASK 3: Aim 6

* Evaluate the performance evaluation of the teleradiology system.

* Continue with utilization of the teleradiology system to increase the statistical power of the analysis.

2.2 Database of Analog Screen Film Mammograms

Appendix IA lists by case number the image database cases together with their ground truth.

2.3 Reader Responses

Appendix IIA shows an example of data collection for reader responses for an individual case in the data file. Appendix IIB illustrates an example of the reader responses for all cases read to date by readers 2 and 6.

2.4 Format for additional clinical and image information to be input into data base (Appendix III)

Additional information as each case to be added to the database including the following: age, family history, history of previous breast surgery. Additional lesion characteristics are the following: size, level of suspicion, characteristics of mass (shape, margins, anad density), characteristics of calcification (morphology, number). This information is being verified and will be added to the database in the first quarter of the second year.

Complete demographic, clinical information will be entered into the database during year 2 using Mammographic Clinical History Sheet (Appendix IIIA). Mammograms have been classified based on abnormalities identified using ACR lexicon. The database will be expanded and completed by adding the mammographic findings using the ACR MagView Program (Appendix IIIB).

2.5 ROC Analysis

Appendix IV details the ROC results of the readers.

2.6 Interactive Grayscale Workstation Display Protocols

Acceptable display protocols are critical in using interactive gray-scale monitors. The acceptability of a protocol for displaying mammographic images may be judged in terms of the rapidity with which a user can accomplish tasks. Image processing and management steps impact the throughput rate of a display protocol, as do the demands of mammographers for specific organizations of images on the screen. One possible display protocol for a two-monitor workstation might be defined as follows. Monitor 1 displays a current exam (craniocaudal (CC), left and right breasts; mediolateral oblique (MLO), left and right breasts). Monitor 2 meanwhile displays either previous exams if available (CC- L&R; MLO - L&R) or previous and current left CC; previous and current left MLO; etc. Data from the radiology and the hospital information systems are displayed. Pre-set window and level functions could aid throughput, as could prefetching (acquiring the patients images from the archive file and storing on the workstation prior to the images being interpreted). At UVA, previous examinations archived on the long-term archive file could take up to 8 minutes to retrieve to the disk file at a specific workstation.

Images will be loaded onto digital tape in a display format consistent with the way in which they will be

reviewed in the clinical setting. Mammograms are typically viewed as mirror images, and if a lesion is identified in one breast the two views of that breast are reviewed.

Examinations will be stored on the digital tape in the following sequences:

1. Left mediolateral Oblique (MLO)

   Right MLO

2. Left craniocaudal (CC)

   Right CC

3. Left MLO and Left CC

4. Right MLO and Right CC

Two significant efforts are required to implement acceptable display protocols for a digital mammography gray-scale workstation; (a) development and evaluation of the protocols; and (b) hardware implementation.

First, we will design several plausible display protocols. Second, we will evaluate the protocols by transferring 40 digitized screen-film mammography cases from the PACS to an optical disk. These cases will be equally divided among masses, microcalcifications, architectural distortions,a nd focal asymmetries. The optical disks will have the images preloaded for each of the display protocols to avoid biasing the protocol evaluation with the frustration of the mammographer in loading a prescribed sequence. Third, four UVA and MCV
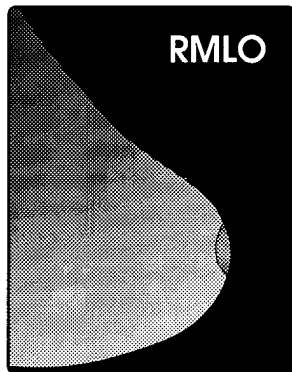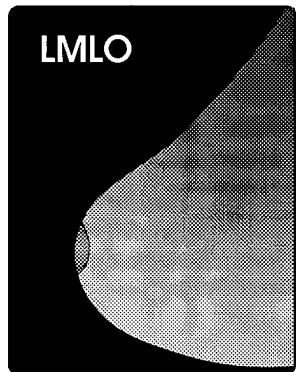
Display A
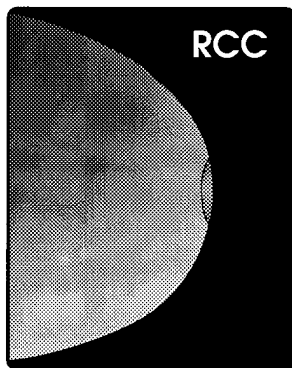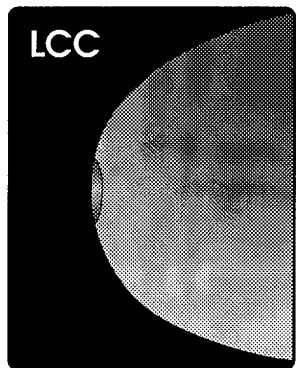
Display B
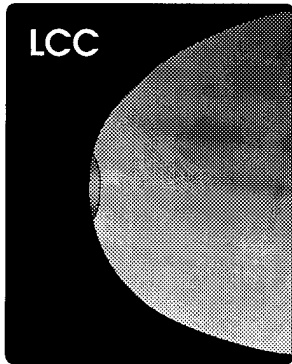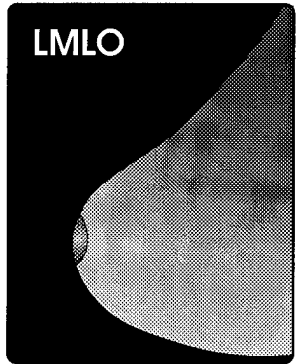
Display C
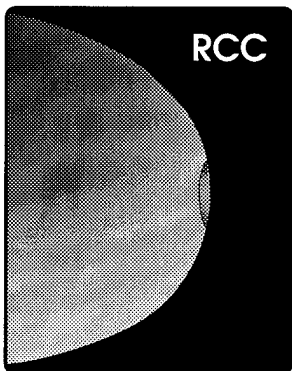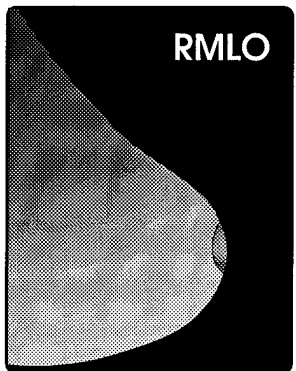
Display D

mammographers will evaluate the lesions using each of the display protocols. A reader rating scale will be used for each case (Example, mass: 1 = definitely acceptable; 2 = probably acceptable; 3 = equivocal; 4 - probably unacceptable; and 4 = definitely unacceptable). The order of each question will be randomized as well as the cases. The reader data will be analyzed for the mean score. The times of initiation and completion of each study will be recorded for calculating the throughput times. A preferred display protocol will be identified on the basis of the mean score and a t-test.

The hardware effort is to implement the best display protocols, as evaluated by the mammography readers, onto a hardware platform. For the two-monitor system, using the UVA system as a testbed, we will incorporate the selected display protocol onto a DSP board or a Hewlett-Packard (HP) accelerator board using toolkits provided by HP. The hardware implementation on the UVA PACS two-monitor systems is not yet approved. HP is just now announcing their new accelerator board; we expect to have it available on-site by February 1996.

We are currently evaluating a set of display protocols.

2.6 Throughput Performance.

Cost-benefit analyses for digital telemammography

lie in the distant future, as they will need to reflect currently nonexistent relationships among costs, availability, efficacy, and quality-of-life features. An opportunity to analyze initial costs, however, lies in the present, created by the availability of the digital mammography environment described in this application. We have devised a cost analysis method in which, for any well-defined system, time can be used to create a relationship between the jobs accomplished per unit of time (the throughput rate) and resources used (costs) to accomplish those jobs. This novel strategy should be applicable to any mammography setting, or for that matter, to any clinical setting.

Table 1 illustrates the starting point for the analysis--a resource allocation table; the "job" in this case is a conventional mammographic examination, defined as beginning with patient registration and ending with the filed report (see table legend). The steps are listed in column 1. The estimated time needed to complete each step (T_i) is given in columns 2 of Table II; T_i is assumed to be normally distributed, therefore 10 observations of each step provide enough sample points for estimating the mean time values. The resources used to accomplish the steps are shown as column headings (refer to table legend), and each resource's points of contribution are indicated in the table by "1." Thus

Table I

Resource Allocation for reading Film Mammography
MCV Mammography Department

Step	Clerk	Tech	Modality	Film Processor	Film Room Personnel	Resident	Radi- ologist	Avg. Time
1	1	0	0	0	0	0	0	T1
2	0	0	0	0	1	0	0	T2
3	0	1	1	0	0	0	0	T3
4	0	1	0	1	0	0	0	T4
5	0	1	0	0	0	0	0	T5
6	0	1	1	1	0	0	0	T6
7	0	0	0	0	0	1	0	T7
8	0	0	0	0	0	1	0	T8
9	0	0	0	0	0	1	1	T9
10*								T10
11	0	0	0	0	0	1	0	T11
12	0	0	0	0	0	1	0	T12
13	0	0	0	0	0	1	0	T13
14	0	0	0	0	0	0	1	T14
15	0	0	0	0	0	0	1	T15
16	0	0	0	0	0	0	1	T16
17	0	0	0	0	1	0	0	T17

Steps used: 1 = Registration; 2 = Prior Film Retrieval; 3 = Image Acquistion; 4 = Film Processed; 5 = Quality Assurance; 6 = Re-acquisition and Processing; 7 = Films Hung; 8 = Review of Clinical Info.; 9 = Films Read; 10 = Additional views or Studies*; 11 = Write Early Reading; 12 = Report Dication; 13 = Notify Clinician; 14 = Review Results with Patients; 15 = Comparison with Prior Films; 16 = Dictate Addendum to Report; 17 = Filing of Report.

*Additional Views for Diagnostic Mammogram
1 = Resources Used
2 = Resources Not Used

Table II

Raw data for Reading Film Mammography Bottleneck Analysis
MCV Mammography Department

T1	12	13	11	10	10	10	10	13	15	11
T2*	1.75									
T3	10	13	12	14	11	13	12	15	6	26
T4	4	5	3	6	5	5	5	5	5	4
T5	3	1	2	2	1	1	2	1	1	2
T6				7				8	7	
T7	0.33	0.66	0.17	0.83	0.25	0.83	0.17	0.25	0.25	0.17
T8	0.33	0.17	0.25	0.083	0.33	0.25	0.33	0.17	0.50	.083
T9	0.25	0.58	0.75	0.25	0.42	0.75	0.33	1.00	1.50	0.41
T10**										
T11	0.50	0.83	0.33	0.17	0.083	0.083	0.25	0.75	0.25	0.17
T12	1.42	0.75	0.83	1.08	0.50	1.83	0.83	2.33	1.75	0.83
T13	2.08	1.5								
T14***	0.42	0.50	1.83	5.33	0.67	0.75	1.5	1.25	0.42	0.75
T15	0.58	0.58	0.75	0.92	1.5	2.25				
T16	2.25	0.58	0.66							
T17#	0.46									

*T2 Calculation: 24 cases retrieved in 42 minutes, 42min/24cases = 1.75 min. per case
** Additional Studies: Ultrasound Study; uses tech, radiologist, and modality as resources.
    Radiologist time: 1) 30 min. 2) 8 min.
    Technologist time: 1) 39 min. 2) 16 min.
***T14 = time required to sign form letters for patients, Direct consultation has not been defined or measured.
Note: Review with Residents: two time trials - 1.83 and 2.00 minutes.

described, a mammographic exam becomes, for our purposes, a system comprised of identifiable resources and steps, and consequently suited to established methods for systems analysis.

One way to characterize the operation of a system is by its throughput rate (measured in jobs per second). Methods we have used previously to analyze PACS operations--bottleneck analysis and Jackson network analysis (35,36)--when applied to mammography will generate the throughput rate for each resource involved in the "job" of interest, and ultimately for the job as a whole. Cost can then be related to the system's throughput rate.

All systems have an operating region which is bounded by upper and lower limits on throughput. To define the upper bound on the throughput, a bottleneck analysis is performed, in which Little's law (37) is used to identify the rate-limiting resource for the case when the whole system is available for one job (eg, for one examination in our model). Little's law states that the mean number of jobs (e) within the system equals the mean throughput rate (λ) multiplied by the mean time in the system (t). Thus, $E = \lambda T$. The mean throughput rate for each resource will increase until one resource is completely utilized (100%); this point of 100% utilization is termed a "bottleneck," ie, the upper bound

beyond which the system's throughput rate cannot increase. To calculate throughputs, one assumes that each resource in turn is the bottleneck. If the film processor in Table 1 is the bottleneck, for example, its throughput is given as $\lambda_{\text{film processor}} = 1/(T_4 + T_6)$. If there are two processors then $\lambda_{\text{film processor}} = 2/(T_4 + T_6)$. The resource with the smallest throughput rate is the true bottleneck. In our example, the bottleneck of the upper bound is the technologist at 0.0371 jobs/second).

The lower bound of the throughput describes the system when more than one demand is placed on it (in our example, the demand for one than one examination). The lower bound throughput is the number of simultaneous demands possible before the next demand is forced to wait for service. Lower-bound values shift depending on the resource being evaluated. for example, we may want to examine the bound placed on our model mammography unit's throughput by the number of clerks (C); in which case, we define T_{clerk} as the time used for the clerk's task(s) and T_{system} as the sum of time used by all other system resources ($T_{\text{tech}} + T_{\text{modality}} + \ldots$etc). We then calculate the lower bound on the mean throughput as $\lambda \gtrdot C/[T_{\text{clerk}} + C (T_{\text{system}})]$.

Figure demonstrates mean throughput rates (λ) as a function of the number of examinations in our model system, lower-bounded in this case by the number of

28

clerks. The area between the upper bound (determined by bottleneck values for the resources) and the lower bound (all resources are busy as of the current demand) is the operating region for the system. Once this region has been defined, it becomes possible to validate its predicted upper and lower bounds in a real system, which will follow the predictions if the model has accurately described the steps and resources necessary to the job. If the real setting behaves differently, the model can be corrected by incorporating the differences in steps or resources.

The costs for each resource can be determined from financial records. The UVA Hospital has recently implemented an accounting system capable of generating detailed cost analyses; for purposes of this study, actual costs will be supplemented with imputed costs for noncommercial equipment. One purpose of the throughput/cost analysis is to establish what economists describe as a "production function." This is a mathematical relationship between the mix of input resources, the total volume of production, and the cost/unit of output. In a typical industrial production situation, one observes that cost/unit is relatively high when volume is very low, but declines as volume increases. At some point there are "diseconomies of scale" (Something like "bottlenecks") and cost/unit

begins to increase. We would expect in our analyses to observe a cost function where the cost per job first decreases as throughput expands and then at some point increases.

3. Conclusions

3.1 Implications of Completed Work.

At the end of the first year of activity, we find researches across the country asking if they could obtain the 400 cases of digitized screen film mammography and the patient data. We plan to complete this database by March 1996. This database will be sent to requesting researchers with prior approval of the U.S. Army for the cost of the 8 mm DAC Tape. All patient data has been appendixed to the digitized screen-film mammography using the DICOM 3.0 Data format standard. We envision that this database will be used by other researchers for the following possible projects.

a. Developing and evaluating computer aid diagnosis algorithms for digital mammography. ROC data on cases completed to date (Appendix IV) have shown that the case selection

reflects adequate range of subtlety.

b. Develop and evaluate improved interactive grayscale workstation display protocols.

c. Utilize the jackknife ROC analysis on a database of proven images and patient data.

d. Evaluate and correlate the type and subtlety of breast lesions versus reader responses on digital and analog images.

e. Evaluate image compression ratios for ROC metrics.

Our first year of ROC analysis for 200 normals and and 200 abnormals of digitized screen-films has reinforced the need for implementing other methods for evaluating reader responses. ROC analysis is very time consuming, often requiring convincing mammographers to participate in such studies. It is often suggested that qualified mammographers can read 200 to 300 cases per day for ROC studies. The existing database of 200 normals and 200 abnormals will serve as a resource for those researchers engaged in

31

evaluating reader analysis.

We have just begun our studies on the use of the ratio of throughput/cost as a means of evaluating cost of telemammography. Throughput (jobs/second) is a production measure used in evaluating computer networks. As the throughput increases in a telemammography system, the cost will increase linearly until a bottleneck is reached. Then the throughput can only increase by spending additional resources to alter the bottlenecks.

Studies are badly needed in determining the optimum image compression ratio for use in telemammography systems. Our initial evaluation is suggesting the use of wavelet algorithms at 50 to 1. Such studies require ROC studies to be accepted by the Radiology profession. A 30 to 1 compression ratio means that a single digital channel (DS-0, 64K bits/sec) can be used to transmitt digital mammography images at less than a minute. Such a compression ratio will also significantly reduce the amount of storage media for long-term storage.

3.2 Recommended Changes

Upon completion of our first year of studying telemammography systems, we have several recommended changes.

First, the jackknife methodology for

conducting ROC analysis should be the method of choice. This method involves the analysis of variance (ANOVA) of the pseudovalues computed by the Quencville-Tikey version of the jackknife. This experimental design permits the comparison of multiple treatments, defined in our study as analog screen-film cases (treatment 1) and grayscale displayed cases (treatment 2).

Second, the statistical power obtained is significant when we have 200 normals and 200 abnormals and with 10 readers. The cases have been carefully selectd and the 10 readers are qualified mammographers. We have learned that completion of this number of cases by all readers is very difficult to accomplish. The readers are not often available when they are needed. The number of cases (400) creates a management difficulty. It may be that 100 normals and 100 abnormals would be better with the use of 15 readers.

REFERENCES

1.   Kerlikowske K, Grady D, Rubin SM, et al. Efficacy of screening mammography: a meta-analysis. JAMA

1995;273:149-154.

2.   Nystrom L, Rutquist LE, Wall S, et al. Breast cancer screening with mammography: overview of Swedish randomized trials. Lancet 1993;341:973-978.

3.   Pelikan S, Moskowitz M. Effects of lead time, length bias, and false-negative assurance on screening for breast cancer. CA 1993;71:1998-2005.

4.   Miller BA, Feuer DJ, Hankey BF. Recent incidence trends for breast cancer in women and relevance of early detection: an update. CA 1993;43:27-41.

5.   Feig SA. Decreased breast cancer mortality through mammographic screening: results of clinical trials. Radiology 1988;167:659-665.

6.   Yaffe MJ. Digital Mammography. Syllabus: A categorical course in physics; technical aspects of breast imaging, 3rd edition.   Arthur G. Haus and Martin J. Yaffe, Editors. RSNA, 80th scientific assembly, Nov 27 - Dec 2, 1994;275-286.

7.   Shtern F. Digital mammography and related technologies: aperspective from the National Cancer Institute. Radiology 1992;183:629-630.

8.   Williams MB, Fajardo LL. digital mammography: performance considerations and curent detector designs. Academic Radiology, in press. Preprint requests to D.W. Phillips, 1224 W. Main St., Suite 605, Charlottesville, VA, 22903, (804) 982-0203.

9. American College of Radiology, National Electronics Manufacturers Association. digital Imaging and Communications in Medicine (DICOM); point-to-point communication support for message exchange. Washington DC: NEMA publication PS 3.9-1993, 1993.

10. Hindel R (Editor). Implementation of the DICOM 3.0 standard. Radiological Society of North America, 2021 Spring Road, Suite 600, Oak Brook, IL 60521, 1994.

11. Prior FW. Specifying DICOM compliance for modality interfaces. RadioGraphics 1993;13:1381-1388.

12. Lodwick GS. PACS and the ACR-NEMA digital image communications standards. Administrative Radiol 1988;5:7-10.

13. Wang Y, Best DE, Hoffman JG, et al. ACR-NEMA digital imaging and communication standards: minimum requirements. Radiology 1988;166:529-532.

14. Arps RB, Truong TK. Comparison of international standards for lossless still image compression. Proc IEEE 1994;82(6):889-899.

15. Good WF, Maitz GS, Gur D. Joint Photographic Experts Group (JPEG) compatible data compression of mammograms. Jr. Digital Imaging 1994;7(3):123-132.

16. Cosman PC, Gray RM, Olshen RA. Evaluating quality of compressed medical images: SNR, subjective rating, and diagnostic accuracy. Proc IEEE 1994;82(6):919-932.

17. Mallat SG. Atheory for multiresolution signal

decomposition: the wavelet representation. IEEE Trans Pattn Analysis and Machine Inte II 1989;11(7):674-693.

18. Vetterli M, Kovacevic J. Wavelets and subband coding. Prentice Hall PTR, Englewood Cliffs, New Jersey 07632, 1995.

19. Chui CK. An introduction to wavelets. Academic Press, Inc., NY, 1992.

20. Daubechies I, Grossman A, Meyer Y. Painless non-orthogonal expansions. J. Math. Phys. 1986;27:1271-1283.

21. Daubechies I. The wavelet transform, time frequency localization and signal analysis. IEEE Trans. Info. Theo 1990;36:961-1005.

22. Chui CK (Editor). Wavelets: a tutorial in theory and applications. Academic Press, Inc. New York, NY, 1992.

23. Akansu AN, Haddad RA. Multiresolution signal decomposition. Academic Press, Inc, New York, NY, 1992;291-346.

24. Siegel EL, Templeton AW, Cook LT, et al. Imaging calibration of laser digitizers, printers, and grayscale displays. RadioGraphics 1992;12:329-335.

25. Dwyer III SJ, Templeton AW, Anderson WH, et al. Teleradiology using switched dial-up networks. IEEE Jr on Slected Areas in Communications 1992;10(7):1161-1172.

26. Templeton AW, Swyer III SJ, Rosenthal SJ, et al. A dial-up digital teleradiology system: Technical considerations and clinical experience. AJR 1991;157:1331-1336.

27. Cox GG, Cook LT, McMillan JH, et al. High resolution 2560 x 2048 x 12 bit digital displays for chest radiography - a comparison with conventional film and digital hardcopy. Radiology 1990;176:771-776.

28. Beard DV, Hemminger BM, Denelsbeck KM, et al. How many screens does a CT workstation need? J Digit Imaging 1994;7:69-76.

29. Bellon E, Houtput W, Bijnens B, et al. Combining fast response and low cost of an intensive care unit viewing station. J Digit Imaging 1994;7:91-94.

30. Beard DV, Hemminger BM, Perry JR, et al. Interpretation of CT studies: single-screen workstation versus film alternator. Radiology 1993;187:565-569.

31. Gur D, Good WF, King JL. Simultaneous and sequential display of ICU AP chest-images. Proc SPIE 1992;1653:159-163.

32. Wilson AJ. Filmless musculoskeletal radiology: why is it taking so long? AJR 1995;165:105-107.

33. Arenson RL, Chakraborty DP, Seshadri SB, et al. The digital imaging workstation. Radiology 1990;176:303-315.

34. Beard DV. Designing a radiology workstation: a focus on navigation during the interpretation task. J Digit Imaging 1990;3:152-163.

35. Stewart BK, Taira RK, Dwyer III SJ, Huang HK. Acquisition and analysis of throughput rates for department-wide PACS.

36. Steward BK and Dwyer III SJ. Electronic archiving system analysis using mean value analysis, Jackson queing models and block oriented network simulation. Proc SPIE 1993;1899:511-517.

37. Stuck BW, Arthurs E. A computer and communications network performance analysis primer. Prentice-Hall Inc, Englewood Clifs, N.J. 1985;1-92.

38. Dorfman DD, Berbaum KS, Metz CE. Receiver Operating Characteristic Reading Analysis: Generalization to the population of readers and patients with the Jackknife method. Investigative Radiology, Sept 1992;27(9):723-731.

APPENDIX I

CASE #	PARENCHYMAL	GROUP	FINDINGS	DIAGNOSIS
001	3	NORMAL		
002	2	NORMAL		
003	3	ABN	CA, AD, FAD	M
004	3	ABN	CA	B
005	3	ABN	CA	M
006	4	ABN	CA	B
007	4	ABN	MASS	B
008	3	ABN	CA	B
009	1	NORMAL		
010	2	NORMAL		
011	1	NORMAL		
012	2	ABN	MASS	M
013	1	ABN	AD, MASS	M
014	2	ABN	CA	M
015	3	NORMAL		
016	4	NORMAL		
017	1	ABN	MASS	B
018	2	ABN	CA	M
019	2	ABN	CA	M
020	1	ABN	MASS	M
021	2	NORMAL		
022	4	NORMAL		
023	2	ABN	FAD	B
024	3	ABN	FAD	B
025	2	NORMAL		
026	1	NORMAL		
027	4	ABN	CA	B
028	1	NORMAL		
029	1	ABN	MASS	B
030	1	ABN	MASS	B
031	3	NORMAL		
032	3	ABN	FAD	B
033	1	ABN	CA	B
034	2	NORMAL		
035	4	NORMAL		
036	2	ABN	FAD	B
037	3	ABN	CA	B
038	3	NORMAL		
039	2	NORMAL		
040	4	ABN	CA	B

041	4	ABN	CA		B
042	2	NORMAL			
043	4	NORMAL			
044	2	NORMAL			
045	3	ABN	FAD		M
046	4	NORMAL			
047	3	NORMAL			
048	2	NORMAL			
049	4	NORMAL			
050	2	NORMAL			
051	2	ABN	CA		B
052	3	NORMAL			
053	1	NORMAL			
054	1	NORMAL			
055	1	ABN	MASS		B
056	1	ABN	CA		B
057	1	ABN	MASS		B
058	2	NORMAL			
059	4	NORMAL			
060	1	NORMAL			
061	4	ABN	CA		B
062	2	NORMAL			
063	1	NORMAL			
064	3	NORMAL			
065	1	ABN	MASS		B
066	3	NORMAL			
067	4	NORMAL			
068	3	ABN	CA		M
069	3	ABN	MASS		B
070	3	NORMAL			
071	3	ABN	CA		B
072	3	ABN	CA		M
073	1	NORMAL			
074	2	ABN	CA		M
075	1	NORMAL			
076	4	NORMAL			
077	4	NORMAL			
078	3	ABN	MASS		B
079	2	ABN	MASS		B
080	2	ABN	MASS		M
081	3	ABN	CA		M
082	3	ABN	CA		B
083	1	NORMAL			
084	2	NORMAL			
085	1	NORMAL			

086	3	ABN	MASS	M
087	3	ABN	CA	M
088	1	ABN	CA	B
089	3	ABN	FAD	B
090	3	ABN	MASS	B
091	4	ABN	CA	M
092	3	NORMAL		
093	1	NORMAL		
094	1	ABN	MASS, CA	M
095	1	ABN	MASS	M
096	4	NORMAL		
097	4	NORMAL		
098	1	NORMAL		
099	4	NORMAL		
100	3	ABN	MASS	M
101	3	NORMAL		
102	3	ABN	AD	M
103	4	ABN	CA	M
104	1	ABN	MASS	M
105	3	NORMAL		
106	2	ABN	MASS	B
107	1	NORMAL		
108	2	ABN	AD	M
109	4	ABN	CA	M
110	1	NORMAL		
111	3	ABN	FAD	M
112	2	NORMAL		
113	3	ABN	FAD	M
114	3	ABN	CA	M
115	2	NORMAL		
116	2	NORMAL		
117	1	NORMAL		
118	1	ABN	MASS	B
119	4	NORMAL		
120	1	NORMAL		
121	3	NORMAL		
122	4	NORMAL		
123	4	ABN	CA	B
124	1	ABN	CA	M
125	3	ABN	CA	B
126	1	ABN	FAD	B
127	4	NORMAL		
128	2	ABN	CA	B
129	4	ABN	CA	M
130	1	NORMAL		

131	3	NORMAL		
132	3	ABN	CA	B
133	1	ABN	CA	M
134	1	ABN	CA	B
135	2	NORMAL		
136	3	NORMAL		
137	2	NORMAL		
138	3	ABN	MASS	M
139	2	ABN	FAD	M
140	3	NORMAL		
141	1	NORMAL		
142	3	ABN	MASS	M
143	4	ABN	MASS	M
144	3	ABN	CA	B
145	4	NORMAL		
146	1	ABN	MASS	M
147	1	NORMAL		
148	2	NORMAL		
149	4	NORMAL		
150	3	NORMAL		
151	1	ABN	MASS	B
152	4	NORMAL		
153	1	ABN	MASS	M
154	4	NORMAL		
155	3	NORMAL		
156	2	ABN		B
157	3	NORMAL		
158	4	NORMAL		
159	4	NORMAL		
160	3	ABN		M
161	2	ABN	CA	B
162	2	NORMAL		
163	3	ABN		B
164	3	ABN	AD	M
165	2	NORMAL		
166	1	ABN	FAD	M
167	4	NORMAL		
168	4	ABN		B
169	4	ABN	CA	B
170	1	ABN	MASS	M
171	3	NORMAL		
172	2	NORMAL		
173	3	NORMAL		
174	4	ABN		B
175	4	ABN	MASS	M

176	4	NORMAL		
177	1	NORMAL		
178	3	ABN	FCC	B
179	2	ABN	CA	B
180	4	NORMAL		
181	2	ABN	MASS	B
182	4	NORMAL		
183	2	NORMAL		
184	3	NORMAL		
185	1	NORMAL		
186	1	ABN	CA	B
187	3	ABN	MASS	M
188	3	ABN	MASS	M
189	4	NORMAL		
190	2	NORMAL		
191	3	ABN	CA	B
192	4	ABN	CA	M
193	3	NORMAL		
194	3	ABN		M
195	3	ABN	MASS	M
196	2	ABN	MASS	M
197	1	NORMAL		
198	2	NORMAL		
199	3	NORMAL		
200	3	ABN	MASS, CA	M
201	2	NORMAL		
202	1	ABN		M
203	2	NORMAL		
204	3	NORMAL		
205	2	ABN		M
206	2	ABN		B
207	3	NORMAL		
208	4	ABN	MASS	B
209	3	NORMAL		
210	2	ABN	CA	M
211	1	NORMAL		
212	4	ABN		M
213	4	NORMAL		
214	4	ABN	CA	M
215	1	NORMAL		
216	4	ABN	CA	M
217	2	NORMAL		
218	4	NORMAL		
219	3	ABN	CA	M
220	1	NORMAL		

221	3	NORMAL		
222	3	ABN		M
223	1	NORMAL		
224	1	NORMAL		
225	1	NORMAL		
226	1	NORMAL		
227	3	NORMAL		
228	3	ABN	CA	M
229	1	NORMAL		
230	3	ABN	FAD	B
231	3	ABN	MASS	M
232	4	NORMAL		
233	3	ABN	MASS	M
234	3	ABN	AD	B
235	1	NORMAL		
236	1	NORMAL		
237	4	ABN	CA	M
238	1	ABN	CA	M
239	2	NORMAL		
240	1	NORMAL		
241	2	ABN		M
242	3	NORMAL		
243	1	ABN	MASS	M
244	2	ABN	MASS	M
245	3	NORMAL		
246	4	ABN		B
247	4	ABN	CA	B
248	1	ABN		B
249	2	ABN	CA	M
250	1	ABN	CA	B
251	3	ABN	MASS	M
252	3	NORMAL		
253	2	ABN	MASS	M
254	1	ABN	CA	M
255	4	NORMAL		
256	4	NORMAL		
257	2	ABN	CA	M
258	1	NORMAL		
259	2	ABN	MASS	B
260	4	NORMAL		
261	3	ABN	CA	B
262	2	NORMAL		
263	1	ABN	MASS	M
264	1	ABN	CA	B
265	4	ABN	CA	M

266	2	NORMAL		
267	1	NORMAL		
268	1	ABN	FAD	B
269	2	NORMAL		
270	2	ABN	CA	M
271	3	ABN	CA	M
272	4	NORMAL		
273	3	ABN	CA	M
274	3	NORMAL		
275	2	ABN	CA	M
276	4	ABN	CA	M
277	2	NORMAL		
278	4	NORMAL		
279	3	NORMAL		
280	1	NORMAL		
281	3	NORMAL		
282	3	ABN	CA	B
283	4	ABN	CA	M
284	4	ABN	CA	M
285	3	NORMAL		
286	2	NORMAL		
287	1	ABN	MASS	M
288	4	ABN	CA	M
289	3	NORMAL		
290	1	ABN	MASS	M
291	2	NORMAL		
292	3	NORMAL		
293	3	ABN	CA	M
294	4	NORMAL		
295	3	ABN	CA	B
296	3	ABN	MASS	B
297	2	NORMAL		
298	4	NORMAL		
299	3	ABN	CA	M
300	1	NORMAL		
301	4	ABN	CA	M
302	4	NORMAL		
303	4	NORMAL		
304	3	ABN	CA	M
305	3	ABN	CA	B
306	2	ABN	MASS	B
307	4	NORMAL		
308	4	ABN	FAD	M
309	1	ABN	MASS	M
310	4	NORMAL		

311	4	ABN	FAD	M
312	2	ABN	MASS	M
313	3	NORMAL		
314	3	ABN	CA	M
315	4	NORMAL		
316	2	ABN	MASS	M
317	2	NORMAL		
318	4	NORMAL		
319	3	NORMAL		
320	3	ABN	CA	B
321	4	NORMAL		
322	2	ABN	CA	M
323	4	ABN	CA	M
324	4	ABN	CA	B
325	2	ABN	FAD	B
326	3	NORMAL		
327	2	NORMAL		
328	3	ABN	CA	B
329	2	NORMAL		
330	2	ABN	MASS	B
331	2	NORMAL		
332	1	NORMAL		
333	4	ABN	MASS	M
334	2	ABN	FAD	M
335	1	ABN	MASS	M
336	2	ABN	MASS	M
337	2	ABN	CA	B
338	2	NORMAL		
339	3	NORMAL		
340	2	NORMAL		
341	3	ABN	CA	M
342	3	NORMAL		
343	3	NORMAL		
344	2	NORMAL		
345	2	NORMAL		
346	3	ABN	CA	M
347	2	NORMAL		
348	2	ABN	MASS	B
349	2	NORMAL		
350	2	NORMAL		

KEY

PARENCHYMAL DENSITY:
1=FATTY
2=SCATTERED FIBROGLANDULAR TISSUE
3=HETEROGENEOUSLY DENSE
4= EXTREMELY DENSE

GROUP:

NORMAL=NORMAL
ABN   = ABNORMAL

FINDINGS:

MASS=MASS
FAD   =FOCAL ASYMMETRIC DENSITY
AD   =ARCHITECTURAL DISTORTION
CA   =CALCIFICATIONS

DIAGNOSIS:

M=MALIGNANT
B=BENIGN

APPENDIX II A

READERS RESPONSES TO CASE 84

MASS	CALCIFICATION	FAD/AD	DIAGNOSIS	READER #
1	5	1	3	6
2	5	1	2	5
2	2	1	1	4
1	5	1	4	3
1	1	2	2	2
1	2	1	2	7
1	5	1	4	10
1	5	1	3	11

KEY TO FINDINGS: **KEY TO DIAGNOSIS**

1=DEFINITELY NOT PRESENT   1=DEFINITELY BENIGN

2=PROBABLY NOT PRESENT   2=PROBABLY BENIGN

3=EQUIVOCAL   3=EQUIVOCAL

4=PROBABLY PRESENT   4=PROBABLY MALIGNANT

5=DEFINITELY PRESENT   5=DEFINITLEY MALIGNANT

APPENDIX II B

READERS SPECIFIC RESPONSES

READER 6

	TRUE NORMALS (149)	TRUE BENIGN (66)	TRUE MALIGNANT (84)
DEFINITELY BENIGN	010	01	00
PROBABLY BENIGN	121	17	14
EQUIVOCAL	017	41	30
PROBABLY MALIGNANT	001	07	25
DEFINITELY MALIGNANT	000	00	15

READER 2

	TRUE NORMALS (149)	TRUE BENIGN (66)	TRUE MALIGNANT (84)
DEFINITELY BENIGN	28	02	01
PROBABLY BENIGN	62	17	06
EQUIVOCAL	59	37	41
PROBABLY MALIGNANT	00	10	23
DEFINITELY MALIGNANT	00	00	13

APPENDIX III A

CLINICAL HISTORY SHEET

MAMMOGRAPHY CLINICAL HISTORY SHEET

HISTORY NO.: _____   DATE OF SERVICE:_____

NAME: LAST_____ FIRST_____M.I._____

ADDRESS:_____ZIP:_____

SSN:_____ DATE OF BIRTH:_____

HOME PHONE NUMBER:(___)____-_____WORK PHONE:(___)____-_____
==
IS THIS YOUR FIRST MAMMOGRAM?   Y   N
IF NO, WHERE WERE YOUR OLD FILMS DONE?   _____
WHEN WAS YOUR LAST MAMMOGRAM?   _____
HOW OLD WERE YOU WHEN YOUR PERIOD STARTED? _____
WHAT IS THE DATE OF YOUR LAST PERIOD?   _____
HAVE YOU EVER HAD A HYSTERECTOMY?   Y   N
DID THEY REMOVE YOUR OVARIES?   Y   N
HOW MANY TIMES HAVE YOU BEEN PREGNANT?   _____
HOW MANY CHILDREN DO YOU HAVE?   _____
HOW OLD WERE YOU WHEN YOUR FIRST CHILD WAS BORN? _____
DO YOU TAKE BIRTH CONTROL PILLS?   _____

HAVE YOU EVER HAD CANCER?   Y   N
IF YES, WHAT KIND OF CANCER?   _____
HAVE ANY OF YOUR FAMILY MEMBERS HAD BREAST CANCER?
MOTHER___ SISTER___ AUNT___ GRANDMOTHER___ OTHER___
GIVE AGE AT DIAGNOSIS: _____

DO YOU HAVE BREAST IMPLANTS?   Y   N
IF YES, WHAT KIND OF IMPLANTS?   _____
DO YOU TAKE HORMONES?   Y   N
WHAT KIND OF HORMONES? ESTROGEN_____ TAMOXIFIN___
PROGESTERONE___ OTHER_____
AT WHAT AGE DID YOU BEGIN TAKING HORMONES? _____

HAVE YOU EVER HAD BREAST SURGERY?   Y   N
IF YES, WHEN AND WHICH BREAST? _____
WHAT WERE THE RESULTS?   _____

HAVE YOU EVER HAD RADIATION THERAPY?   Y   N
IF YES, WHICH BREAST AND IN WHAT YEAR?   _____

HAVE YOU EVER HAD A BREAST REMOVED?   Y   N
IF YES, WHICH BREAST?   _____

HAVE YOU FOUND ANY NEW LUMPS IN YOUR BREAST? Y   N
IF YES, WHICH BREAST?   _____
HOW LONG HAVE YOU HAD THE LUMP?   _____
HAS THE LUMP CHANGED?   _____

DO YOU HAVE ANY OTHER NEW BREAST PROBLEMS?   Y   N
IF YES, PLEASE DESCRIBE:_____
WHEN DID THE PROBLEM START?   _____

51

TECH ID:_____

CLINICAL FINDINGS:

SCREENING___   FOLLOW UP AT SHORT INTERVAL__

ADDITIONAL VIEWS___

REVIEW OF OUTSIDE STUDY___   PRE-RADIATION THERAPY___

PROBLEMS INDICATED:

PALPABLE ABNORMALITY___   BLOODY DISCHARGE___

NON BLOODY DISCHARGE___   BREAST IMPLANT PROBLEM___

SKIN THICKENING OR RETRACTION___   NIPPLE ABNORMALITY___

PAIN___   CANCER ELSEWHERE___   LARGE AXILLARY LYMPH NODES___

OTHER_____

ANGLE OF OBLIQUITY ON MLO: 30   45   60

BREAST ULTRASOUND: (PLEASE CIRCLE)

RIGHT   LEFT   BOTH

ADDITIONAL VIEWS: (PLEASE INDICATE WHICH BREAST R OR L)

1)_____   2)_____

3)_____   4)_____

PLEASE CIRCLE MACHINE USED:

NELSON CLINIC   STONY POINT

I   II   III   IV   I   II

VIEW	MAS	KVP	+ OR -	KG	MM
R CC					
L CC					
R MLO					
L MLO					

COMMENTS:_____

APPENDIX III B

MAMMOGRAPHIC FINDINGS

MagView™

Finding check-off sheets

Patient ID: _____

Patient Name: _____

Examination Date: _____

❑ Prior study dates compared: ___/___/___ ___/___/___ ___/___/___

Finding⁼ _____ of _____

❑ Negative exam

❑ Mammogram
❑ Ultrasound
❑ Ductography

Tissue Density

❑ Almost entirely fat
❑ Scattered fibroglandular densities
❑ Heterogeneously dense
❑ Extremely dense

Recommendation

❑ Normal interval screening in____ months or by age____.
❑ Any decision to biopsy should be based on clinical assessment

Initials:_____

❑ Non-Negative Finding

❑ Finding correlates to clinical exam finding in ❑L ❑R ❑B breast(s) at _____ (location)

❑ **Follow-up**
 ❑ Follow-up of procedure
 ❑ Lumpectomy
 ❑ Excisional biopsy
 ❑ Mastectomy
 ❑ Needle biopsy
 ❑ Radiation Therapy

❑ **Follow-up of prior finding** in ❑L ❑R ❑B breast(s) at _____ (location).

❑ **Change**
 ❑ No significant changes
 ❑ Increase in size
 ❑ Decrease in size
 ❑ Increase in number of calcifications

❑ Decrease in number of calcifications
❑ Less defined
❑ More defined
❑ Completely removed
❑ Partially removed

Finding Side: ❑ Left   ❑ Right   ❑ Both   ❑ Multiple similar findings: Approximate number:_____

Mammogram

❑ Not seen on mammogram

Tissue Density (choose one)
❑ Almost entirely fat
❑ Scattered fibroglandular densities
❑ Heterogeneously dense
❑ Extremely dense

Mass Shape (choose one)
❑ Round
❑ Oval
❑ Lobular
❑ Irregular
❑ Architectural distortion
❑ Tubular density/solitary dilated duct
❑ Intramammary lymph node
❑ Asymmetric breast tissue
❑ Focal asymmetric density

Margins (choose one)
❑ Circumscribed
❑ Microlobulated
❑ Obscured
❑ Indistinct
❑ Spiculated

Density (choose one)
❑ High density
❑ Low density
❑ Isodense
❑ Fat containing

Calcifications
❑ Skin
❑ Vascular
❑ Coarse
❑ Large rod-like
❑ Large round
❑ Eggshell or rim
❑ Milk of calcium
❑ Dystrophic
❑ Punctate
❑ Amorphous or indistinct
❑ Heterogeneous or pleomorphic
❑ Fine and/or branching
❑ Spherical or lucent-centered
❑ Suture

Distribution (choose one)
❑ Grouped or clustered
❑ Segmental
❑ Regional
❑ Linear
❑ Diffuse/scattered

Other findings
❑ Nipple retraction
❑ Skin thickening
❑ Trabecular thickening
❑ Skin lesion
❑ Axilliary adenopathy
❑ Skin retraction
❑ Architectural distortion
❑ Hematoma
❑ Post surgical scar

Implant Findings
❑ Asymmetric implant
❑ Calcified implant
❑ Distorted implant
❑ Fibrosed Implant
❑ Herniated implant
❑ Ruptured implant
❑ Free silicone
❑ Capsular contraction

Ductography

☐ Not seen on Ductogram

☐ Intraluminal filling defect
☐ Duct ectasia
☐ Multiple filling defects
☐ Abrupt duct termination

☐ Extravasation
☐ Duct narrowing
☐ Cyst fill

Ultrasound

☐ Not seen on Ultrasound

Modifiers
☐ Anechoic
☐ Hypoechoic
☐ Hyperechoic
☐ Isoechoic
☐ Mixed echogenicity
☐ Posterior acoustic shadowing
☐ Posterior acoustic enhancement

Finding
☐ Simple cyst
☐ Complex Cyst
☐ Intracystic lesion
☐ Duct ectasia
☐ Solid mass

Size and Location

Size _____ millimeters

Location _____ o'clock

☐ Subareolar
☐ Central
☐ Axillary tail

Depth
☐ Anterior
☐ Middle
☐ Posterior

Assessment and Recommendation

Additional Evaluation Needed
☐ Cyst aspiration
☐ Additional projections
☐ Magnification views
☐ Spot compression
☐ Clinical correlation
☐ Ultrasound exam

Benign
☐ Normal interval screening in _____ months
☐ Cyst aspiration
☐ Any decision to biopsy should be based on clinical assessment

Probably Benign
☐ Short interval follow-up in _____ months

Suspicious
☐ Biopsy should be considered
☐ Needle localization and bio
☐ Histology using core biopsy

Malignant
☐ Biopsy should be considered
☐ Needle localization and bio
☐ Histology using core biopsy
☐ Appropriate action should be taken

Notes

_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____
_____ _____ _____

Initials: _____

APPENDIX IV A

READER STATUS REPORT

READER	CASES READ (AS OF 09-30-95)
02	1-299
03	1-299
04	1-299
05	1-350
06	1-300
07	1-300
09	1-250
10	1-200
11	1-200
12	1-100
13	1-100

APPENDIX IV B

ROC RESULTS OF READERS FOR ANALOG IMAGES

APPENDIX IV

B I

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
O F   A   B I N O R M A L   R O C   C U R V E
F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 2, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   59.

RESPONSE DATA:
```
 CATEGORY                      1      2      3      4      5
 ACTUALLY NEGATIVE CASES     44.    44.    53.    2.     6.
 ACTUALLY POSITIVE CASES      3.     3.     8.    10.    35.
```

OBSERVED OPERATING POINTS:
```
 FPF: 0.0000 0.0403 0.0537 0.4094 0.7047 1.0000
 TPF: 0.0000 0.5932 0.7627 0.8983 0.9492 1.0000
```

INITIAL VALUES OF PARAMETERS:
A= 1.3744   B= 0.5371
Z(K)= −0.5376   0.2287   1.6104   1.7480
LOGL= −271.0403
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.4609   B= 0.6171
Z(K)= −0.5266   0.2289   1.4998   1.9286
LOGL= −264.3502
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE−COVARIANCE MATRIX:
```
A       0.0525  0.0197  0.0050  0.0052  0.0045  0.0009
B       0.0197  0.0173  0.0020  0.0011 −0.0052 −0.0117
Z( 1)   0.0050  0.0020  0.0116  0.0062  0.0030  0.0021
Z( 2)   0.0052  0.0011  0.0062  0.0105  0.0055  0.0047
Z( 3)   0.0045 −0.0052  0.0030  0.0055  0.0234  0.0231
Z( 4)   0.0009 −0.0117  0.0021  0.0047  0.0231  0.0397
```

CORRELATION MATRIX:
```
A       1.0000  0.6523  0.2014  0.2210  0.1284  0.0187
B       0.6523  1.0000  0.1390  0.0823 −0.2592 −0.4476
Z( 1)   0.2014  0.1390  1.0000  0.5645  0.1807  0.0962
Z( 2)   0.2210  0.0823  0.5645  1.0000  0.3543  0.2323
Z( 3)   0.1284 −0.2592  0.1807  0.3543  1.0000  0.7586
Z( 4)   0.0187 −0.4476  0.0962  0.2323  0.7586  1.0000
```

AREA = 0.8931   STD. DEV.(AREA) = 0.0290

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE−POSITIVE FRACTION AT EACH SPECIFIED
FALSE−POSITIVE FRACTION:

```
        FPF        TPF          (LOWER BOUND, UPPER BOUND)

       0.005      0.4487      (    0.2635  ,     0.6460    )
       0.010      0.5100      (    0.3324  ,     0.6855    )
       0.020      0.5766      (    0.4124  ,     0.7283    )
       0.030      0.6179      (    0.4638  ,     0.7551    )
       0.040      0.6481      (    0.5019  ,     0.7751    )
       0.050      0.6721      (    0.5322  ,     0.7911    )
       0.060      0.6919      (    0.5573  ,     0.8046    )
       0.070      0.7088      (    0.5787  ,     0.8163    )
       0.080      0.7236      (    0.5973  ,     0.8266    )
       0.090      0.7367      (    0.6137  ,     0.8359    )
       0.100      0.7485      (    0.6284  ,     0.8443    )
       0.110      0.7592      (    0.6416  ,     0.8520    )
       0.120      0.7690      (    0.6537  ,     0.8591    )
       0.130      0.7781      (    0.6647  ,     0.8656    )
       0.140      0.7865      (    0.6749  ,     0.8718    )
       0.150      0.7943      (    0.6844  ,     0.8775    )
       0.200      0.8268      (    0.7234  ,     0.9015    )
       0.250      0.8520      (    0.7531  ,     0.9200    )
       0.300      0.8723      (    0.7771  ,     0.9348    )
       0.400      0.9040      (    0.8147  ,     0.9568    )
       0.500      0.9280      (    0.8442  ,     0.9719    )
       0.600      0.9471      (    0.8693  ,     0.9826    )
       0.700      0.9628      (    0.8921  ,     0.9901    )
       0.800      0.9762      (    0.9142  ,     0.9952    )
       0.900      0.9878      (    0.9384  ,     0.9985    )
       0.950      0.9934      (    0.9538  ,     0.9995    )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT              LOWER BOUND              UPPER BOUND
  ( FPF ,    TPF )                  ( FPF ,    TPF )          ( FPF ,    TPF )

(0.0269, 0.6067)                   (0.0102, 0.5118)          (0.0620, 0.6956)
(0.0668, 0.7038)                   (0.0360, 0.6369)          (0.1151, 0.7644)
(0.4095, 0.9065)                   (0.3338, 0.8841)          (0.4887, 0.9256)
(0.7008, 0.9629)                   (0.6238, 0.9511)          (0.7696, 0.9723)
```
1   R O C F I T (JUNE 1993 VERSION) :

  M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

    DATA DESCRIPTION: Reader 2, MicroCalcifications

    DATA COLLECTED IN 5 CATEGORIES
    WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

    NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   82.

    RESPONSE DATA:
     CATEGORY   1   2   3   4   5
     ACTUALLY NEGATIVE CASES   127.   14.   5.   0.   3.
     ACTUALLY POSITIVE CASES   12.   6.   4.   11.   49.

    OBSERVED OPERATING POINTS:
     FPF: 0.0000 0.0201 0.0201 0.0537 0.1477 1.0000

TPF: 0.0000 0.5976 0.7317 0.7805 0.8537 1.0000

          INITIAL VALUES OF PARAMETERS:
A= 1.8080   B= 0.6820
Z(K)= 1.0466   1.6104   1.9514   2.0514
LOGL= -191.9226
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
A= 1.8169   B= 0.6938
Z(K)= 1.0526   1.5531   1.8560   2.2459
LOGL= -184.4330
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

          VARIANCE-COVARIANCE MATRIX:
A   0.1216   0.0618   0.0150   0.0032 -0.0095 -0.0326
B   0.0618   0.0410   0.0038 -0.0066 -0.0169 -0.0348
Z(1)   0.0150   0.0038   0.0159   0.0128   0.0112   0.0092
Z(2)   0.0032 -0.0066   0.0128   0.0233   0.0235   0.0254
Z(3)   -0.0095 -0.0169   0.0112   0.0235   0.0350   0.0406
Z(4)   -0.0326 -0.0348   0.0092   0.0254   0.0406   0.0667

          CORRELATION MATRIX:
A   1.0000   0.8756   0.3411   0.0600 -0.1452 -0.3622
B   0.8756   1.0000   0.1502 -0.2124 -0.4452 -0.6656
Z(1)   0.3411   0.1502   1.0000   0.6645   0.4752   0.2833
Z(2)   0.0600 -0.2124   0.6645   1.0000   0.8240   0.6448
Z(3)   -0.1452 -0.4452   0.4752   0.8240   1.0000   0.8409
Z(4)   -0.3622 -0.6656   0.2833   0.6448   0.8409   1.0000

       AREA = 0.9323   STD. DEV.(AREA) = 0.0231
1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

   FPF   TPF   (LOWER BOUND, UPPER BOUND)

   0.005   0.5118   (0.3057   ,   0.7147   )
   0.010   0.5803   (0.3971   ,   0.7473   )
   0.020   0.6524   (0.4987   ,   0.7843   )
   0.030   0.6956   (0.5595   ,   0.8089   )
   0.040   0.7264   (0.6018   ,   0.8279   )
   0.050   0.7503   (0.6334   ,   0.8438   )
   0.060   0.7697   (0.6581   ,   0.8574   )
   0.070   0.7861   (0.6781   ,   0.8693   )
   0.080   0.8001   (0.6947   ,   0.8799   )
   0.090   0.8123   (0.7088   ,   0.8894   )
   0.100   0.8232   (0.7209   ,   0.8979   )
   0.110   0.8329   (0.7315   ,   0.9056   )
   0.120   0.8417   (0.7409   ,   0.9126   )
   0.130   0.8498   (0.7493   ,   0.9190   )
   0.140   0.8571   (0.7569   ,   0.9248   )
   0.150   0.8639   (0.7638   ,   0.9302   )
   0.200   0.8912   (0.7911   ,   0.9511   )
   0.250   0.9114   (0.8111   ,   0.9654   )
   0.300   0.9269   (0.8269   ,   0.9753   )

```
            0.400      0.9496       (    0.8517  ,    0.9874   )
            0.500      0.9654       (    0.8715  ,    0.9938   )
            0.600      0.9768       (    0.8887  ,    0.9972   )
            0.700      0.9854       (    0.9047  ,    0.9989   )
            0.800      0.9918       (    0.9210  ,    0.9997   )
            0.900      0.9966       (    0.9395  ,    0.9999   )
            0.950      0.9985       (    0.9519  ,    1.0000   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0124, 0.6021)	(0.0030, 0.4632)	(0.0410, 0.7291)
(0.0317, 0.7017)	(0.0131, 0.6083)	(0.0682, 0.7834)
(0.0602, 0.7702)	(0.0320, 0.7026)	(0.1049, 0.8282)
(0.1463, 0.8614)	(0.0968, 0.8199)	(0.2103, 0.8958)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
       O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 2, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   27.

RESPONSE DATA:
```
 CATEGORY                      1      2      3      4      5
 ACTUALLY NEGATIVE CASES      93.    27.    10.    10.     9.
 ACTUALLY POSITIVE CASES       6.     0.     2.     8.    11.
```

OBSERVED OPERATING POINTS:
```
 FPF: 0.0000 0.0604 0.1275 0.1946 0.3758 1.0000
 TPF: 0.0000 0.4074 0.7037 0.7778 0.7778 1.0000
```

         INITIAL VALUES OF PARAMETERS:
A= 1.3079   B= 0.8539
Z(K)= 0.3160   0.8608   1.1383   1.5517
LOGL= −209.1670
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER   5 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
A= 1.1742   B= 0.8234
Z(K)= 0.3269   0.8058   1.0795   1.6264
LOGL= −208.0945
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

         VARIANCE−COVARIANCE MATRIX:
A   0.1161 0.0609 0.0099 0.0079 0.0057 −0.0022

```

```
B   0.0609   0.0596   0.0035 -0.0003 -0.0037 -0.0152
Z(1)   0.0099   0.0035   0.0109   0.0082   0.0071   0.0053
Z(2)   0.0079 -0.0003   0.0082   0.0129   0.0114   0.0095
Z(3)   0.0057 -0.0037   0.0071   0.0114   0.0155   0.0134
Z(4)   -0.0022 -0.0152   0.0053   0.0095   0.0134   0.0283

         CORRELATION MATRIX:
A   1.0000   0.7313   0.2783   0.2036   0.1354 -0.0388
B   0.7313   1.0000   0.1356 -0.0097 -0.1210 -0.3698
Z(1)   0.2783   0.1356   1.0000   0.6919   0.5454   0.3029
Z(2)   0.2036 -0.0097   0.6919   1.0000   0.8055   0.4983
Z(3)   0.1354 -0.1210   0.5454   0.8055   1.0000   0.6430
Z(4)   -0.0388 -0.3698   0.3029   0.4983   0.6430   1.0000
```

AREA =   0.8177      STD. DEV.(AREA) =   0.0524

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1718 | ( 0.0344 , | 0.4705 ) |
| 0.010 | 0.2291 | ( 0.0648 , | 0.5128 ) |
| 0.020 | 0.3025 | ( 0.1171 , | 0.5617 ) |
| 0.030 | 0.3539 | ( 0.1613 , | 0.5946 ) |
| 0.040 | 0.3945 | ( 0.1999 , | 0.6205 ) |
| 0.050 | 0.4284 | ( 0.2341 , | 0.6422 ) |
| 0.060 | 0.4577 | ( 0.2647 , | 0.6614 ) |
| 0.070 | 0.4836 | ( 0.2924 , | 0.6786 ) |
| 0.080 | 0.5068 | ( 0.3176 , | 0.6944 ) |
| 0.090 | 0.5279 | ( 0.3407 , | 0.7091 ) |
| 0.100 | 0.5473 | ( 0.3618 , | 0.7228 ) |
| 0.110 | 0.5652 | ( 0.3813 , | 0.7357 ) |
| 0.120 | 0.5819 | ( 0.3994 , | 0.7480 ) |
| 0.130 | 0.5974 | ( 0.4162 , | 0.7596 ) |
| 0.140 | 0.6120 | ( 0.4318 , | 0.7707 ) |
| 0.150 | 0.6258 | ( 0.4464 , | 0.7812 ) |
| 0.200 | 0.6849 | ( 0.5071 , | 0.8276 ) |
| 0.250 | 0.7321 | ( 0.5534 , | 0.8652 ) |
| 0.300 | 0.7712 | ( 0.5905 , | 0.8955 ) |
| 0.400 | 0.8330 | ( 0.6483 , | 0.9396 ) |
| 0.500 | 0.8798 | ( 0.6937 , | 0.9673 ) |
| 0.600 | 0.9166 | ( 0.7329 , | 0.9840 ) |
| 0.700 | 0.9458 | ( 0.7695 , | 0.9933 ) |
| 0.800 | 0.9691 | ( 0.8068 , | 0.9979 ) |
| 0.900 | 0.9871 | ( 0.8502 , | 0.9997 ) |
| 0.950 | 0.9943 | ( 0.8798 , | 0.9999 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0519, 0.4345) | (0.0252, 0.3313) | (0.0974, 0.5424) |

```
       (0.1402, 0.6123)          (0.0929, 0.5337)        (0.2016, 0.6865)
       (0.2102, 0.6952)          (0.1519, 0.6284)        (0.2798, 0.7561)
       (0.3719, 0.8173)          (0.2974, 0.7692)        (0.4515, 0.8586)
1                          R O C F I T (JUNE 1993 VERSION) :

     M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
           O F   A   B I N O R M A L   R O C   C U R V E
                  F R O M   R A T I N G   D A T A


        DATA DESCRIPTION: Reader 2, Benign or Malignant

        DATA COLLECTED IN  5 CATEGORIES
        WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

        NO. OF ACTUALLY NEGATIVE CASES =  149.     NO. OF ACTUALLY POSITIVE CASES =  150.

        RESPONSE DATA:
         CATEGORY                      1      2      3      4      5
         ACTUALLY NEGATIVE CASES     28.    62.    59.     0.     0.
         ACTUALLY POSITIVE CASES      3.    23.    78.    33.    13.

        OBSERVED OPERATING POINTS:
         FPF: 0.0000 0.0000 0.0000 0.3960 0.8121 1.0000
         TPF: 0.0000 0.0867 0.3067 0.8267 0.9800 1.0000

                 INITIAL VALUES OF PARAMETERS:
        A= 1.2603     B= 0.8325
        Z(K)= -0.8855     0.2634     2.6112     2.7112
        LOGL= -397.9249
        CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


        PROCEDURE CONVERGES AFTER   7 ITERATIONS.


                 FINAL VALUES OF PARAMETERS:
        A= 1.2232     B= 0.6858
        Z(K)= -0.9217     0.3090     2.5500     3.7878
        LOGL= -345.4767
        CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


                 VARIANCE-COVARIANCE MATRIX:
        A       0.0189  0.0045  0.0052  0.0060  0.0056 -0.0005
        B       0.0045  0.0099  0.0027 -0.0001 -0.0269 -0.0459
        Z( 1)   0.0052  0.0027  0.0140  0.0051 -0.0023 -0.0073
        Z( 2)   0.0060 -0.0001  0.0051  0.0103  0.0087  0.0091
        Z( 3)   0.0056 -0.0269 -0.0023  0.0087  0.1115  0.1582
        Z( 4) -0.0005 -0.0459 -0.0073  0.0091  0.1582  0.2801


                 CORRELATION MATRIX:
        A       1.0000  0.3270  0.3178  0.4283  0.1216 -0.0072
        B       0.3270  1.0000  0.2319 -0.0120 -0.8074 -0.8706
        Z( 1)   0.3178  0.2319  1.0000  0.4245 -0.0585 -0.1170
        Z( 2)   0.4283 -0.0120  0.4245  1.0000  0.2583  0.1695
        Z( 3)   0.1216 -0.8074 -0.0585  0.2583  1.0000  0.8953
        Z( 4) -0.0072 -0.8706 -0.1170  0.1695  0.8953  1.0000


            AREA =  0.8435      STD. DEV.(AREA) =  0.0258
1

        ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
        BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
        TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.2934	(0.1514 ,	0.4775)
0.010	0.3548	(0.2065 ,	0.5294)
0.020	0.4264	(0.2779 ,	0.5864)
0.030	0.4734	(0.3282 ,	0.6222)
0.040	0.5089	(0.3680 ,	0.6488)
0.050	0.5379	(0.4012 ,	0.6702)
0.060	0.5623	(0.4298 ,	0.6881)
0.070	0.5836	(0.4550 ,	0.7037)
0.080	0.6024	(0.4776 ,	0.7174)
0.090	0.6193	(0.4981 ,	0.7297)
0.100	0.6347	(0.5169 ,	0.7409)
0.110	0.6488	(0.5341 ,	0.7512)
0.120	0.6618	(0.5502 ,	0.7608)
0.130	0.6739	(0.5651 ,	0.7696)
0.140	0.6852	(0.5791 ,	0.7779)
0.150	0.6958	(0.5922 ,	0.7857)
0.200	0.7409	(0.6482 ,	0.8191)
0.250	0.7766	(0.6924 ,	0.8460)
0.300	0.8062	(0.7287 ,	0.8684)
0.400	0.8531	(0.7859 ,	0.9045)
0.500	0.8894	(0.8299 ,	0.9322)
0.600	0.9187	(0.8659 ,	0.9541)
0.700	0.9432	(0.8970 ,	0.9713)
0.800	0.9641	(0.9253 ,	0.9846)
0.900	0.9822	(0.9534 ,	0.9942)
0.950	0.9906	(0.9692 ,	0.9977)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0001, 0.0847)	(0.0000, 0.0185)	(0.0030, 0.2537)
(0.0054, 0.2996)	(0.0007, 0.1650)	(0.0290, 0.4695)
(0.3787, 0.8441)	(0.3059, 0.8093)	(0.4560, 0.8744)
(0.8217, 0.9682)	(0.7548, 0.9551)	(0.8757, 0.9780)

APPENDIX IV

B II

 R O C F I T (JUNE 1993 VERSION) :

MAXIMUM   LIKELIHOOD   ESTIMATION
    OF   A   BINORMAL   ROC   CURVE
        FROM   RATING   DATA

DATA DESCRIPTION: Reader 3, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   59.

RESPONSE DATA:
 CATEGORY   1   2   3   4   5
 ACTUALLY NEGATIVE CASES 100.   41.   1.   6.   1.
 ACTUALLY POSITIVE CASES   6.   6.   3.   10.   34.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0067 0.0470 0.0537 0.3289 1.0000
 TPF: 0.0000 0.5763 0.7458 0.7966 0.8983 1.0000

        INITIAL VALUES OF PARAMETERS:
A= 1.5514   B= 0.5243
Z(K)= 0.4426   1.6104   1.6752   2.4728
LOGL= -197.8084
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

        FINAL VALUES OF PARAMETERS:
A= 1.5534   B= 0.5279
Z(K)= 0.4474   1.5513   1.7104   2.5634
LOGL= -196.4182
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

        VARIANCE-COVARIANCE MATRIX:
A   0.0741 0.0289 0.0066 0.0035 0.0017 -0.0209
B   0.0289 0.0197 0.0019 -0.0042 -0.0064 -0.0298
Z(1)   0.0066 0.0019 0.0113 0.0065 0.0060 0.0035
Z(2)   0.0035 -0.0042 0.0065 0.0246 0.0240 0.0263
Z(3)   0.0017 -0.0064 0.0060 0.0240 0.0296 0.0336
Z(4) -0.0209 -0.0298 0.0035 0.0263 0.0336 0.1096

        CORRELATION MATRIX:
A   1.0000 0.7573 0.2287 0.0831 0.0367 -0.2316
B   0.7573 1.0000 0.1262 -0.1906 -0.2655 -0.6429
Z(1)   0.2287 0.1262 1.0000 0.3888 0.3294 0.0989
Z(2)   0.0831 -0.1906 0.3888 1.0000 0.8887 0.5059
Z(3)   0.0367 -0.2655 0.3294 0.8887 1.0000 0.5900
Z(4) -0.2316 -0.6429 0.0989 0.5059 0.5900 1.0000

     AREA = 0.9152   STD. DEV.(AREA) = 0.0292

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

```
     FPF        TPF        (LOWER BOUND, UPPER BOUND)

    0.005      0.5767      (    0.3939  ,    0.7440   )
    0.010      0.6274      (    0.4620  ,    0.7721   )
    0.020      0.6805      (    0.5340  ,    0.8031   )
    0.030      0.7124      (    0.5769  ,    0.8229   )
    0.040      0.7353      (    0.6072  ,    0.8379   )
    0.050      0.7533      (    0.6305  ,    0.8500   )
    0.060      0.7681      (    0.6492  ,    0.8603   )
    0.070      0.7806      (    0.6649  ,    0.8692   )
    0.080      0.7915      (    0.6782  ,    0.8770   )
    0.090      0.8011      (    0.6898  ,    0.8841   )
    0.100      0.8097      (    0.7001  ,    0.8905   )
    0.110      0.8175      (    0.7092  ,    0.8963   )
    0.120      0.8246      (    0.7175  ,    0.9016   )
    0.130      0.8312      (    0.7250  ,    0.9065   )
    0.140      0.8372      (    0.7319  ,    0.9111   )
    0.150      0.8429      (    0.7383  ,    0.9153   )
    0.200      0.8663      (    0.7643  ,    0.9329   )
    0.250      0.8844      (    0.7841  ,    0.9462   )
    0.300      0.8992      (    0.8001  ,    0.9565   )
    0.400      0.9222      (    0.8256  ,    0.9715   )
    0.500      0.9398      (    0.8461  ,    0.9816   )
    0.600      0.9542      (    0.8641  ,    0.9885   )
    0.700      0.9664      (    0.8811  ,    0.9934   )
    0.800      0.9771      (    0.8985  ,    0.9968   )
    0.900      0.9871      (    0.9188  ,    0.9989   )
    0.950      0.9923      (    0.9329  ,    0.9996   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND              UPPER BOUND
    ( FPF ,    TPF )            ( FPF ,    TPF )          ( FPF ,    TPF )

(0.0052, 0.5793)              (0.0007, 0.4434)          (0.0278, 0.7063)
(0.0436, 0.7423)              (0.0203, 0.6817)          (0.0848, 0.7963)
(0.0604, 0.7687)              (0.0315, 0.7164)          (0.1068, 0.8151)
(0.3273, 0.9061)              (0.2559, 0.8863)          (0.4056, 0.9233)
1                                 R O C F I T (JUNE 1993 VERSION) :
```

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
     O F   A   B I N O R M A L   R O C   C U R V E
          F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 3, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   82.

RESPONSE DATA:
```
 CATEGORY                        1       2       3       4       5
 ACTUALLY NEGATIVE CASES      135.    10.     0.      0.      4.
 ACTUALLY POSITIVE CASES       29.     1.     1.      5.     46.
```

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0268 0.0268 0.0268 0.0940 1.0000

TPF: 0.0000 0.5610 0.6220 0.6341 0.6463 1.0000

          INITIAL VALUES OF PARAMETERS:
A= 0.7642   B= 0.2756
Z(K)= 1.3170   1.7297   1.8297   1.9297
LOGL= -142.8031
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
A= 0.7916   B= 0.3089
Z(K)= 1.3225   1.7410   1.7930   2.0498
LOGL= -140.5911
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

          VARIANCE-COVARIANCE MATRIX:
A   0.0733   0.0328   0.0093 -0.0032 -0.0052 -0.0172
B   0.0328   0.0204   0.0023 -0.0066 -0.0080 -0.0164
Z(1)   0.0093   0.0023   0.0204   0.0171   0.0168   0.0150
Z(2)   -0.0032 -0.0066   0.0171   0.0314   0.0315   0.0327
Z(3)   -0.0052 -0.0080   0.0168   0.0315   0.0340   0.0357
Z(4)   -0.0172 -0.0164   0.0150   0.0327   0.0357   0.0536

          CORRELATION MATRIX:
A   1.0000   0.8490   0.2413 -0.0675 -0.1051 -0.2742
B   0.8490   1.0000   0.1123 -0.2591 -0.3030 -0.4970
Z(1)   0.2413   0.1123   1.0000   0.6764   0.6365   0.4546
Z(2)   -0.0675 -0.2591   0.6764   1.0000   0.9640   0.7976
Z(3)   -0.1051 -0.3030   0.6365   0.9640   1.0000   0.8360
Z(4)   -0.2742 -0.4970   0.4546   0.7976   0.8360   1.0000

     AREA =   0.7753   STD. DEV.(AREA) =   0.0699

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

     FPF   TPF   (LOWER BOUND, UPPER BOUND)

    0.005   0.4983   (0.3469   ,   0.6499   )
    0.010   0.5290   (0.3929   ,   0.6618   )
    0.020   0.5624   (0.4405   ,   0.6785   )
    0.030   0.5833   (0.4681   ,   0.6918   )
    0.040   0.5989   (0.4870   ,   0.7032   )
    0.050   0.6115   (0.5011   ,   0.7136   )
    0.060   0.6222   (0.5121   ,   0.7231   )
    0.070   0.6314   (0.5210   ,   0.7319   )
    0.080   0.6396   (0.5284   ,   0.7401   )
    0.090   0.6470   (0.5347   ,   0.7478   )
    0.100   0.6538   (0.5400   ,   0.7551   )
    0.110   0.6601   (0.5447   ,   0.7620   )
    0.120   0.6659   (0.5489   ,   0.7686   )
    0.130   0.6713   (0.5526   ,   0.7749   )
    0.140   0.6765   (0.5559   ,   0.7808   )
    0.150   0.6813   (0.5589   ,   0.7865   )
    0.200   0.7025   (0.5707   ,   0.8119   )
    0.250   0.7202   (0.5791   ,   0.8332   )
    0.300   0.7356   (0.5856   ,   0.8516   )

```
0.400    0.7622      (    0.5954  ,    0.8821   )
0.500    0.7857      (    0.6029  ,    0.9070   )
0.600    0.8078      (    0.6094  ,    0.9281   )
0.700    0.8298      (    0.6155  ,    0.9466   )
0.800    0.8535      (    0.6219  ,    0.9635   )
0.900    0.8825      (    0.6298  ,    0.9795   )
0.950    0.9032      (    0.6357  ,    0.9879   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0202, 0.5629)	(0.0062, 0.5073)	(0.0552, 0.6173)
(0.0365, 0.5939)	(0.0156, 0.5501)	(0.0761, 0.6366)
(0.0408, 0.6001)	(0.0184, 0.5582)	(0.0817, 0.6410)
(0.0930, 0.6491)	(0.0545, 0.6165)	(0.1487, 0.6807)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
        O F   A   B I N O R M A L   R O C   C U R V E
              F R O M   R A T I N G   D A T A

 DATA DESCRIPTION: Reader 3, FAS/AD

 DATA COLLECTED IN 5 CATEGORIES
 WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

 NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   27.

 RESPONSE DATA:
  CATEGORY   1   2   3   4   5
  ACTUALLY NEGATIVE CASES   100.   14.   0.   21.   14.
  ACTUALLY POSITIVE CASES   11.   1.   0.   11.   4.

 OBSERVED OPERATING POINTS:
  FPF: 0.0000 0.0940 0.2349 0.3289 1.0000
  TPF: 0.0000 0.1481 0.5556 0.5926 1.0000

         INITIAL VALUES OF PARAMETERS:
 A= 1.0544   B= 1.5447
 Z(K)= 0.4426   0.7225   1.3170
 LOGL= -180.4581
 CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

 PROCEDURE CONVERGES AFTER 4 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
 A= 0.9177   B= 1.3982
 Z(K)= 0.4487   0.6788   1.3417
 LOGL= -179.8747
 CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

         VARIANCE-COVARIANCE MATRIX:
 A   0.1578 0.1213 0.0189 0.0149 -0.0004
```

```
B        0.1213   0.1589   0.0070   0.0008  -0.0213
Z( 1)    0.0189   0.0070   0.0113   0.0099   0.0069
Z( 2)    0.0149   0.0008   0.0099   0.0119   0.0092
Z( 3)   -0.0004  -0.0213   0.0069   0.0092   0.0207


         CORRELATION MATRIX:
A        1.0000   0.7660   0.4469   0.3448  -0.0065
B        0.7660   1.0000   0.1651   0.0182  -0.3724
Z( 1)    0.4469   0.1651   1.0000   0.8521   0.4504
Z( 2)    0.3448   0.0182   0.8521   1.0000   0.5831
Z( 3)   -0.0065  -0.3724   0.4504   0.5831   1.0000
```

AREA = 0.7033   STD. DEV.(AREA) = 0.0578

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.0036	(0.0000 ,	0.1186)
0.010	0.0098	(0.0001 ,	0.1550)
0.020	0.0253	(0.0010 ,	0.2037)
0.030	0.0434	(0.0033 ,	0.2402)
0.040	0.0629	(0.0071 ,	0.2707)
0.050	0.0834	(0.0127 ,	0.2978)
0.060	0.1044	(0.0201 ,	0.3225)
0.070	0.1259	(0.0290 ,	0.3456)
0.080	0.1475	(0.0395 ,	0.3675)
0.090	0.1692	(0.0514 ,	0.3885)
0.100	0.1909	(0.0645 ,	0.4089)
0.110	0.2126	(0.0785 ,	0.4287)
0.120	0.2341	(0.0933 ,	0.4482)
0.130	0.2555	(0.1088 ,	0.4673)
0.140	0.2766	(0.1248 ,	0.4863)
0.150	0.2975	(0.1410 ,	0.5051)
0.200	0.3979	(0.2227 ,	0.5969)
0.250	0.4900	(0.2980 ,	0.6845)
0.300	0.5734	(0.3635 ,	0.7640)
0.400	0.7136	(0.4698 ,	0.8857)
0.500	0.8206	(0.5554 ,	0.9551)
0.600	0.8982	(0.6304 ,	0.9864)
0.700	0.9506	(0.7009 ,	0.9972)
0.800	0.9819	(0.7716 ,	0.9997)
0.900	0.9966	(0.8498 ,	1.0000)
0.950	0.9994	(0.8981 ,	1.0000)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0898, 0.1689)	(0.0522, 0.0881)	(0.1446, 0.2863)
(0.2486, 0.4875)	(0.1860, 0.3705)	(0.3210, 0.6056)
(0.3268, 0.6142)	(0.2554, 0.4994)	(0.4051, 0.7197)

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
        F R O M   R A T I N G   D A T A

   DATA DESCRIPTION: Reader 3, Benign or Malignant

   DATA COLLECTED IN 5 CATEGORIES
   WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

   NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES = 150.

   RESPONSE DATA:
    CATEGORY   1   2   3   4   5
    ACTUALLY NEGATIVE CASES   93.   42.   9.   5.   0.
    ACTUALLY POSITIVE CASES   24.   42.   37.   27.   20.

   OBSERVED OPERATING POINTS:
    FPF: 0.0000 0.0000 0.0336 0.0940 0.3758 1.0000
    TPF: 0.0000 0.1333 0.3133 0.5600 0.8400 1.0000

          INITIAL VALUES OF PARAMETERS:
   A= 1.2702   B= 0.8959
   Z(K)= 0.3160   1.3170   1.8313   2.7112
   LOGL= -378.3870
   CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

   PROCEDURE CONVERGES AFTER   5 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
   A= 1.2787   B= 0.8858
   Z(K)= 0.3172   1.2914   1.9619   2.7109
   LOGL= -376.3607
   CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

          VARIANCE-COVARIANCE MATRIX:
   A   0.0312   0.0155   0.0106   0.0052 -0.0025 -0.0137
   B   0.0155   0.0171   0.0034 -0.0060 -0.0167 -0.0309
   Z(1)   0.0106   0.0034   0.0109   0.0067   0.0044   0.0016
   Z(2)   0.0052 -0.0060   0.0067   0.0165   0.0189   0.0234
   Z(3) -0.0025 -0.0167   0.0044   0.0189   0.0361   0.0480
   Z(4) -0.0137 -0.0309   0.0016   0.0234   0.0480   0.0866

          CORRELATION MATRIX:
   A   1.0000   0.6727   0.5739   0.2270 -0.0744 -0.2638
   B   0.6727   1.0000   0.2506 -0.3583 -0.6697 -0.8032
   Z(1)   0.5739   0.2506   1.0000   0.4988   0.2195   0.0519
   Z(2)   0.2270 -0.3583   0.4988   1.0000   0.7734   0.6186
   Z(3) -0.0744 -0.6697   0.2195   0.7734   1.0000   0.8585
   Z(4) -0.2638 -0.8032   0.0519   0.6186   0.8585   1.0000

       AREA = 0.8308   STD. DEV.(AREA) = 0.0256

   ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
   BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
   TRUE-POSITIVE FRACTION AT EACH SPECIFIED
   FALSE-POSITIVE FRACTION:

```
     FPF        TPF        (LOWER BOUND,  UPPER BOUND)

    0.005      0.1578      (   0.0665   ,    0.3070    )
    0.010      0.2170      (   0.1098   ,    0.3680    )
    0.020      0.2943      (   0.1759   ,    0.4400    )
    0.030      0.3491      (   0.2280   ,    0.4880    )
    0.040      0.3926      (   0.2717   ,    0.5251    )
    0.050      0.4291      (   0.3095   ,    0.5556    )
    0.060      0.4606      (   0.3431   ,    0.5818    )
    0.070      0.4885      (   0.3731   ,    0.6048    )
    0.080      0.5135      (   0.4004   ,    0.6255    )
    0.090      0.5362      (   0.4253   ,    0.6443    )
    0.100      0.5570      (   0.4482   ,    0.6616    )
    0.110      0.5761      (   0.4694   ,    0.6775    )
    0.120      0.5940      (   0.4891   ,    0.6924    )
    0.130      0.6106      (   0.5075   ,    0.7064    )
    0.140      0.6261      (   0.5247   ,    0.7195    )
    0.150      0.6408      (   0.5408   ,    0.7319    )
    0.200      0.7031      (   0.6090   ,    0.7852    )
    0.250      0.7522      (   0.6622   ,    0.8275    )
    0.300      0.7923      (   0.7055   ,    0.8619    )
    0.400      0.8542      (   0.7729   ,    0.9132    )
    0.500      0.8995      (   0.8245   ,    0.9479    )
    0.600      0.9335      (   0.8665   ,    0.9710    )
    0.700      0.9593      (   0.9024   ,    0.9858    )
    0.800      0.9785      (   0.9342   ,    0.9945    )
    0.900      0.9921      (   0.9638   ,    0.9988    )
    0.950      0.9969      (   0.9790   ,    0.9997    )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT         LOWER BOUND              UPPER BOUND
   (  FPF ,    TPF  )           (  FPF ,    TPF  )       (  FPF ,    TPF  )

   (0.0034, 0.1308)             (0.0005, 0.0512)         (0.0164, 0.2704)
   (0.0249, 0.3230)             (0.0098, 0.2150)         (0.0560, 0.4486)
   (0.0983, 0.5536)             (0.0613, 0.4647)         (0.1493, 0.6398)
   (0.3755, 0.8408)             (0.3010, 0.7929)         (0.4551, 0.8807)
```

APPENDIX IV

B III

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
O F   A   B I N O R M A L   R O C   C U R V E
F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 4, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   59.

RESPONSE DATA:
CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	38.	61.	40.	8.	2.
ACTUALLY POSITIVE CASES	2.	3.	16.	6.	32.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0134 0.0671 0.3356 0.7450 1.0000
 TPF: 0.0000 0.5424 0.6441 0.9153 0.9661 1.0000

        INITIAL VALUES OF PARAMETERS:
A= 1.4749   B= 0.6394
Z(K)= −0.6584   0.4241   1.4979   2.2142
LOGL= −263.4115
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

        FINAL VALUES OF PARAMETERS:
A= 1.4939   B= 0.6633
Z(K)= −0.6526   0.4028   1.5744   2.1027
LOGL= −262.5013
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

        VARIANCE−COVARIANCE MATRIX:
A	0.0536	0.0202	0.0051	0.0058	0.0046	−0.0010
B	0.0202	0.0175	0.0020	0.0010	−0.0061	−0.0151
Z(1)	0.0051	0.0020	0.0122	0.0052	0.0026	0.0015
Z(2)	0.0058	0.0010	0.0052	0.0108	0.0064	0.0055
Z(3)	0.0046	−0.0061	0.0026	0.0064	0.0251	0.0257
Z(4)	−0.0010	−0.0151	0.0015	0.0055	0.0257	0.0492

        CORRELATION MATRIX:
A	1.0000	0.6613	0.1977	0.2416	0.1252	−0.0192
B	0.6613	1.0000	0.1374	0.0691	−0.2914	−0.5166
Z(1)	0.1977	0.1374	1.0000	0.4489	0.1491	0.0602
Z(2)	0.2416	0.0691	0.4489	1.0000	0.3873	0.2376
Z(3)	0.1252	−0.2914	0.1491	0.3873	1.0000	0.7321
Z(4)	−0.0192	−0.5166	0.0602	0.2376	0.7321	1.0000

     AREA = 0.8934   STD. DEV.(AREA) = 0.0282

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE−POSITIVE FRACTION AT EACH SPECIFIED
FALSE−POSITIVE FRACTION:

```
        FPF         TPF        (LOWER BOUND,  UPPER BOUND)

      0.005      0.4149      (   0.2371   ,    0.6125   )
      0.010      0.4803      (   0.3068   ,    0.6577   )
      0.020      0.5523      (   0.3895   ,    0.7066   )
      0.030      0.5972      (   0.4434   ,    0.7371   )
      0.040      0.6302      (   0.4837   ,    0.7598   )
      0.050      0.6564      (   0.5159   ,    0.7780   )
      0.060      0.6781      (   0.5426   ,    0.7933   )
      0.070      0.6967      (   0.5654   ,    0.8065   )
      0.080      0.7129      (   0.5853   ,    0.8181   )
      0.090      0.7272      (   0.6029   ,    0.8284   )
      0.100      0.7401      (   0.6187   ,    0.8378   )
      0.110      0.7518      (   0.6329   ,    0.8464   )
      0.120      0.7625      (   0.6459   ,    0.8542   )
      0.130      0.7724      (   0.6578   ,    0.8615   )
      0.140      0.7815      (   0.6688   ,    0.8683   )
      0.150      0.7900      (   0.6789   ,    0.8746   )
      0.200      0.8253      (   0.7210   ,    0.9007   )
      0.250      0.8524      (   0.7531   ,    0.9206   )
      0.300      0.8742      (   0.7789   ,    0.9363   )
      0.400      0.9076      (   0.8194   ,    0.9590   )
      0.500      0.9324      (   0.8509   ,    0.9743   )
      0.600      0.9517      (   0.8774   ,    0.9847   )
      0.700      0.9672      (   0.9012   ,    0.9917   )
      0.800      0.9799      (   0.9240   ,    0.9962   )
      0.900      0.9905      (   0.9480   ,    0.9989   )
      0.950      0.9951      (   0.9627   ,    0.9996   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND              UPPER BOUND
    ( FPF ,    TPF )            ( FPF ,    TPF )          ( FPF ,    TPF )

  (0.0177, 0.5395)             (0.0056, 0.4250)         (0.0477, 0.6509)
  (0.0577, 0.6735)             (0.0297, 0.5962)         (0.1032, 0.7440)
  (0.3436, 0.8900)             (0.2720, 0.8624)         (0.4213, 0.9134)
  (0.7430, 0.9730)             (0.6685, 0.9627)         (0.8077, 0.9808)
1                              R O C F I T (JUNE 1993 VERSION) :
```

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 4, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   82.

RESPONSE DATA:
```
  CATEGORY                      1      2      3      4      5
  ACTUALLY NEGATIVE CASES      34.    89.    21.     2.     3.
  ACTUALLY POSITIVE CASES       3.    27.    12.     7.    33.
```

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0201 0.0336 0.1745 0.7718 1.0000

```
     TPF: 0.0000 0.4024 0.4878 0.6341 0.9634 1.0000

          INITIAL VALUES OF PARAMETERS:
A=  1.1938     B=  0.7160
Z(K)= -0.7446     0.9365     1.8313     2.0514
LOGL=  -270.8926
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


PROCEDURE CONVERGES AFTER   4 ITERATIONS.



          FINAL VALUES OF PARAMETERS:
A=  1.1283     B=  0.7053
Z(K)= -0.7614     0.9868     1.6973     1.9788
LOGL=  -269.4543
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE



          VARIANCE-COVARIANCE MATRIX:
A       0.0311   0.0109   0.0060   0.0065   0.0040   0.0022
B       0.0109   0.0120   0.0028  -0.0015  -0.0078  -0.0114
Z( 1)   0.0060   0.0028   0.0129   0.0037   0.0019   0.0011
Z( 2)   0.0065  -0.0015   0.0037   0.0140   0.0125   0.0125
Z( 3)   0.0040  -0.0078   0.0019   0.0125   0.0273   0.0283
Z( 4)   0.0022  -0.0114   0.0011   0.0125   0.0283   0.0381



          CORRELATION MATRIX:
A       1.0000   0.5610   0.3014   0.3090   0.1366   0.0635
B       0.5610   1.0000   0.2234  -0.1165  -0.4327  -0.5335
Z( 1)   0.3014   0.2234   1.0000   0.2754   0.1009   0.0480
Z( 2)   0.3090  -0.1165   0.2754   1.0000   0.6388   0.5420
Z( 3)   0.1366  -0.4327   0.1009   0.6388   1.0000   0.8771
Z( 4)   0.0635  -0.5335   0.0480   0.5420   0.8771   1.0000


       AREA =  0.8217       STD. DEV.(AREA) =  0.0323

 1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:


     FPF       TPF        (LOWER BOUND, UPPER BOUND)

    0.005     0.2455     (    0.1253  ,    0.4095    )
    0.010     0.3040     (    0.1756  ,    0.4627    )
    0.020     0.3743     (    0.2422  ,    0.5231    )
    0.030     0.4213     (    0.2898  ,    0.5623    )
    0.040     0.4575     (    0.3277  ,    0.5920    )
    0.050     0.4872     (    0.3595  ,    0.6162    )
    0.060     0.5125     (    0.3869  ,    0.6369    )
    0.070     0.5347     (    0.4112  ,    0.6550    )
    0.080     0.5545     (    0.4330  ,    0.6711    )
    0.090     0.5724     (    0.4527  ,    0.6857    )
    0.100     0.5887     (    0.4708  ,    0.6991    )
    0.110     0.6037     (    0.4875  ,    0.7114    )
    0.120     0.6177     (    0.5030  ,    0.7229    )
    0.130     0.6307     (    0.5174  ,    0.7336    )
    0.140     0.6429     (    0.5310  ,    0.7437    )
    0.150     0.6544     (    0.5437  ,    0.7532    )
    0.200     0.7036     (    0.5981  ,    0.7942    )
    0.250     0.7430     (    0.6415  ,    0.8271    )
    0.300     0.7760     (    0.6777  ,    0.8545    )
```

```
            0.400    0.8289      (   0.7362  ,   0.8976   )
            0.500    0.8704      (   0.7831  ,   0.9297   )
            0.600    0.9043      (   0.8233  ,   0.9540   )
            0.700    0.9329      (   0.8596  ,   0.9724   )
            0.800    0.9574      (   0.8944  ,   0.9859   )
            0.900    0.9789      (   0.9309  ,   0.9951   )
            0.950    0.9890      (   0.9526  ,   0.9982   )
```

         ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
         CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
         CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND              UPPER BOUND
    ( FPF ,   TPF )             ( FPF ,   TPF )          ( FPF ,   TPF )

   (0.0239, 0.3946)            (0.0091, 0.2956)         (0.0552, 0.5009)
   (0.0448, 0.4725)            (0.0216, 0.3831)         (0.0848, 0.5633)
   (0.1619, 0.6672)            (0.1114, 0.6059)         (0.2252, 0.7244)
   (0.7768, 0.9521)            (0.7049, 0.9342)         (0.8375, 0.9658)
```
1   R O C F I T (JUNE 1993 VERSION) :

    M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
        O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

    DATA DESCRIPTION: Reader 4, FAS/AD

    DATA COLLECTED IN 5 CATEGORIES
    WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

    NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   27.

    RESPONSE DATA:
      CATEGORY   1   2   3   4   5
      ACTUALLY NEGATIVE CASES   22.   58.   19.   26.   24.
      ACTUALLY POSITIVE CASES   3.   6.   3.   0.   15.

    OBSERVED OPERATING POINTS:
     FPF: 0.0000 0.1611 0.3356 0.4631 0.8523 1.0000
     TPF: 0.0000 0.5556 0.5556 0.6667 0.8889 1.0000

            INITIAL VALUES OF PARAMETERS:
    A= 0.5715   B= 0.5571
    Z(K)= -1.0466   0.0924   0.4241   0.9900
    LOGL= -260.0469
    CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

    PROCEDURE CONVERGES AFTER   4 ITERATIONS.

            FINAL VALUES OF PARAMETERS:
    A= 0.5870   B= 0.5037
    Z(K)= -1.0604   0.1050   0.4573   0.9660
    LOGL= -259.7316
    CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

            VARIANCE-COVARIANCE MATRIX:
    A   0.0526 0.0065 0.0041 0.0035 0.0036 0.0040
```

```
B   0.0065   0.0229   0.0031   0.0000 -0.0010 -0.0032
Z(1)   0.0041   0.0031   0.0159   0.0051   0.0039   0.0027
Z(2)   0.0035   0.0000   0.0051   0.0104   0.0082   0.0063
Z(3)   0.0036 -0.0010   0.0039   0.0082   0.0111   0.0086
Z(4)   0.0040 -0.0032   0.0027   0.0063   0.0086   0.0148

          CORRELATION MATRIX:
A   1.0000   0.1880   0.1413   0.1485   0.1479   0.1443
B   0.1880   1.0000   0.1599   0.0013 -0.0638 -0.1762
Z(1)   0.1413   0.1599   1.0000   0.3950   0.2940   0.1776
Z(2)   0.1485   0.0013   0.3950   1.0000   0.7640   0.5067
Z(3)   0.1479 -0.0638   0.2940   0.7640   1.0000   0.6694
Z(4)   0.1443 -0.1762   0.1776   0.5067   0.6694   1.0000

        AREA =   0.6999   STD. DEV.(AREA) =   0.0700
```
1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

```
   FPF        TPF         (LOWER BOUND,  UPPER BOUND)

  0.005      0.2386      (   0.0642   ,    0.5396    )
  0.010      0.2793      (   0.0911   ,    0.5652    )
  0.020      0.3272      (   0.1285   ,    0.5940    )
  0.030      0.3592      (   0.1568   ,    0.6128    )
  0.040      0.3840      (   0.1802   ,    0.6272    )
  0.050      0.4045      (   0.2006   ,    0.6391    )
  0.060      0.4222      (   0.2187   ,    0.6495    )
  0.070      0.4378      (   0.2352   ,    0.6586    )
  0.080      0.4519      (   0.2504   ,    0.6670    )
  0.090      0.4647      (   0.2645   ,    0.6746    )
  0.100      0.4766      (   0.2776   ,    0.6817    )
  0.110      0.4877      (   0.2901   ,    0.6884    )
  0.120      0.4980      (   0.3018   ,    0.6947    )
  0.130      0.5078      (   0.3130   ,    0.7008    )
  0.140      0.5171      (   0.3236   ,    0.7065    )
  0.150      0.5259      (   0.3338   ,    0.7120    )
  0.200      0.5648      (   0.3790   ,    0.7371    )
  0.250      0.5977      (   0.4173   ,    0.7592    )
  0.300      0.6267      (   0.4506   ,    0.7794    )
  0.400      0.6771      (   0.5072   ,    0.8162    )
  0.500      0.7214      (   0.5547   ,    0.8500    )
  0.600      0.7625      (   0.5968   ,    0.8817    )
  0.700      0.8026      (   0.6363   ,    0.9120    )
  0.800      0.8439      (   0.6763   ,    0.9411    )
  0.900      0.8911      (   0.7230   ,    0.9695    )
  0.950      0.9216      (   0.7558   ,    0.9838    )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND                UPPER BOUND
   ( FPF ,    TPF )             ( FPF ,    TPF )           ( FPF ,    TPF )

 (0.1670, 0.5400)              (0.1143, 0.4922)          (0.2333, 0.5872)
```

```
       (0.3237, 0.6393)           (0.2533, 0.5996)        (0.4011, 0.6775)
       (0.4582, 0.7034)           (0.3804, 0.6677)        (0.5377, 0.7371)
       (0.8555, 0.8689)           (0.7919, 0.8405)        (0.9045, 0.8936)
```

MAXIMUM LIKELIHOOD ESTIMATION
OF A BINORMAL ROC CURVE
FROM RATING DATA

DATA DESCRIPTION: Reader 4, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES = 150.

RESPONSE DATA:
```
 CATEGORY                    1      2      3      4      5
 ACTUALLY NEGATIVE CASES   27.    90.    32.    0.     0.
 ACTUALLY POSITIVE CASES    7.    45.    61.    25.    12.
```

OBSERVED OPERATING POINTS:
```
 FPF: 0.0000 0.0000 0.0000 0.2148 0.8188 1.0000
 TPF: 0.0000 0.0800 0.2467 0.6533 0.9533 1.0000
```

```
        INITIAL VALUES OF PARAMETERS:
A=  0.9927     B=  0.7668
Z(K)= -0.9107     0.7898     2.6112     2.7112
LOGL=  -384.2195
```
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 7 ITERATIONS.

```
        FINAL VALUES OF PARAMETERS:
A=  0.9878     B=  0.6626
Z(K)= -0.9335     0.8314     2.5567     3.6335
LOGL=  -347.6042
```
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

```
        VARIANCE-COVARIANCE MATRIX:
A        0.0162   0.0042   0.0057   0.0058   0.0026 -0.0026
B        0.0042   0.0074   0.0031 -0.0018 -0.0188 -0.0317
Z( 1)    0.0057   0.0031   0.0143   0.0038 -0.0029 -0.0079
Z( 2)    0.0058 -0.0018   0.0038   0.0126   0.0148   0.0178
Z( 3)    0.0026 -0.0188 -0.0029   0.0148   0.0832   0.1112
Z( 4) -0.0026 -0.0317 -0.0079   0.0178   0.1112   0.2013
```

```
        CORRELATION MATRIX:
A        1.0000   0.3869   0.3724   0.4085   0.0700 -0.0449
B        0.3869   1.0000   0.2980 -0.1812 -0.7584 -0.8210
Z( 1)    0.3724   0.2980   1.0000   0.2866 -0.0835 -0.1477
Z( 2)    0.4085 -0.1812   0.2866   1.0000   0.4581   0.3540
Z( 3)    0.0700 -0.7584 -0.0835   0.4581   1.0000   0.8593
Z( 4) -0.0449 -0.8210 -0.1477   0.3540   0.8593   1.0000
```

```
     AREA =  0.7949      STD. DEV.(AREA) =  0.0279
```
1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED

FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.2360	(0.1295 ,	0.3783)
0.010	0.2898	(0.1764 ,	0.4291)
0.020	0.3545	(0.2378 ,	0.4868)
0.030	0.3979	(0.2817 ,	0.5241)
0.040	0.4315	(0.3167 ,	0.5525)
0.050	0.4593	(0.3463 ,	0.5756)
0.060	0.4830	(0.3720 ,	0.5953)
0.070	0.5039	(0.3949 ,	0.6126)
0.080	0.5226	(0.4156 ,	0.6280)
0.090	0.5395	(0.4344 ,	0.6419)
0.100	0.5551	(0.4518 ,	0.6547)
0.110	0.5695	(0.4680 ,	0.6666)
0.120	0.5829	(0.4830 ,	0.6776)
0.130	0.5954	(0.4971 ,	0.6879)
0.140	0.6072	(0.5105 ,	0.6977)
0.150	0.6183	(0.5230 ,	0.7069)
0.200	0.6665	(0.5775 ,	0.7470)
0.250	0.7058	(0.6218 ,	0.7800)
0.300	0.7391	(0.6592 ,	0.8082)
0.400	0.7940	(0.7203 ,	0.8547)
0.500	0.8384	(0.7698 ,	0.8921)
0.600	0.8760	(0.8123 ,	0.9229)
0.700	0.9091	(0.8507 ,	0.9485)
0.800	0.9389	(0.8876 ,	0.9698)
0.900	0.9669	(0.9263 ,	0.9870)
0.950	0.9811	(0.9493 ,	0.9941)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0001, 0.0778)	(0.0000, 0.0226)	(0.0029, 0.2013)
(0.0053, 0.2400)	(0.0009, 0.1399)	(0.0232, 0.3701)
(0.2029, 0.6689)	(0.1466, 0.6146)	(0.2704, 0.7199)
(0.8247, 0.9459)	(0.7579, 0.9267)	(0.8785, 0.9609)

APPENDIX IV

B IV

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
        O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 5, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   59.

RESPONSE DATA:
 CATEGORY   1   2   3   4   5
 ACTUALLY NEGATIVE CASES   104.   33.   7.   3.   2.
 ACTUALLY POSITIVE CASES   5.   10.   2.   13.   29.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0134 0.0336 0.0805 0.3020 1.0000
 TPF: 0.0000 0.4915 0.7119 0.7458 0.9153 1.0000

            INITIAL VALUES OF PARAMETERS:
A= 1.7869   B= 0.7670
Z(K)= 0.5182   1.4017   1.8313   2.2142
LOGL= -210.7154
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

            FINAL VALUES OF PARAMETERS:
A= 1.7799   B= 0.7652
Z(K)= 0.5196   1.4144   1.6996   2.3413
LOGL= -207.9325
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

        VARIANCE-COVARIANCE MATRIX:
A   0.0959 0.0452 0.0101 0.0059 0.0006 -0.0215
B   0.0452 0.0331 0.0029 -0.0047 -0.0105 -0.0319
Z(1)   0.0101 0.0029 0.0116 0.0074 0.0065 0.0043
Z(2)   0.0059 -0.0047 0.0074 0.0205 0.0198 0.0212
Z(3)   0.0006 -0.0105 0.0065 0.0198 0.0282 0.0323
Z(4) -0.0215 -0.0319 0.0043 0.0212 0.0323 0.0723

        CORRELATION MATRIX:
A   1.0000 0.8029 0.3034 0.1335 0.0116 -0.2584
B   0.8029 1.0000 0.1497 -0.1790 -0.3442 -0.6523
Z(1)   0.3034 0.1497 1.0000 0.4809 0.3579 0.1499
Z(2)   0.1335 -0.1790 0.4809 1.0000 0.8239 0.5521
Z(3)   0.0116 -0.3442 0.3579 0.8239 1.0000 0.7148
Z(4) -0.2584 -0.6523 0.1499 0.5521 0.7148 1.0000

        AREA = 0.9213   STD. DEV.(AREA) = 0.0241

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

```
      FPF        TPF        (LOWER BOUND,  UPPER BOUND)

    0.005      0.4241      (   0.2255  ,    0.6448   )
    0.010      0.4998      (   0.3092  ,    0.6905   )
    0.020      0.5824      (   0.4096  ,    0.7405   )
    0.030      0.6333      (   0.4741  ,    0.7722   )
    0.040      0.6701      (   0.5212  ,    0.7958   )
    0.050      0.6988      (   0.5580  ,    0.8149   )
    0.060      0.7224      (   0.5879  ,    0.8310   )
    0.070      0.7423      (   0.6128  ,    0.8448   )
    0.080      0.7595      (   0.6340  ,    0.8570   )
    0.090      0.7745      (   0.6524  ,    0.8678   )
    0.100      0.7879      (   0.6686  ,    0.8775   )
    0.110      0.7999      (   0.6829  ,    0.8862   )
    0.120      0.8108      (   0.6958  ,    0.8942   )
    0.130      0.8207      (   0.7075  ,    0.9015   )
    0.140      0.8298      (   0.7181  ,    0.9081   )
    0.150      0.8381      (   0.7278  ,    0.9143   )
    0.200      0.8720      (   0.7668  ,    0.9387   )
    0.250      0.8969      (   0.7955  ,    0.9557   )
    0.300      0.9160      (   0.8182  ,    0.9678   )
    0.400      0.9437      (   0.8529  ,    0.9832   )
    0.500      0.9625      (   0.8796  ,    0.9915   )
    0.600      0.9758      (   0.9018  ,    0.9960   )
    0.700      0.9854      (   0.9216  ,    0.9984   )
    0.800      0.9923      (   0.9403  ,    0.9995   )
    0.900      0.9971      (   0.9599  ,    0.9999   )
    0.950      0.9988      (   0.9717  ,    1.0000   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND               UPPER BOUND
    ( FPF ,    TPF )            ( FPF ,    TPF )           ( FPF ,    TPF )

(0.0096, 0.4954)              (0.0021, 0.3391)          (0.0348, 0.6524)
(0.0446, 0.6842)              (0.0213, 0.5901)          (0.0852, 0.7676)
(0.0786, 0.7573)              (0.0450, 0.6855)          (0.1284, 0.8192)
(0.3017, 0.9166)              (0.2324, 0.8889)          (0.3789, 0.9387)
```
1   R O C F I T (JUNE 1993 VERSION) :

  M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
        O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

  DATA DESCRIPTION: Reader 5, MicroCalcifications

  DATA COLLECTED IN 5 CATEGORIES
  WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

  NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   82.

  RESPONSE DATA:
   CATEGORY   1   2   3   4   5
   ACTUALLY NEGATIVE CASES   116.   19.   3.   3.   8.
   ACTUALLY POSITIVE CASES   3.   27.   12.   7.   33.

  OBSERVED OPERATING POINTS:
   FPF: 0.0000 0.0537 0.0738 0.0940 0.2215 1.0000

TPF: 0.0000 0.4024 0.4878 0.6341 0.9634 1.0000

```
          INITIAL VALUES OF PARAMETERS:
A=  3.6757    B=  2.4979
Z(K)=  0.7670    1.3170    1.4482    1.6104
LOGL=  -227.2513
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE
```

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

```
          FINAL VALUES OF PARAMETERS:
A=  3.6478    B=  2.4614
Z(K)=  0.7655    1.3378    1.4848    1.5864
LOGL=  -225.6613
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE
```

```
          VARIANCE-COVARIANCE MATRIX:
A        0.4865   0.3474   0.0421   0.0053  -0.0113  -0.0232
B        0.3474   0.3153   0.0132  -0.0285  -0.0443  -0.0555
Z( 1)    0.0421   0.0132   0.0131   0.0099   0.0091   0.0086
Z( 2)    0.0053  -0.0285   0.0099   0.0184   0.0194   0.0203
Z( 3)   -0.0113  -0.0443   0.0091   0.0194   0.0226   0.0239
Z( 4)   -0.0232  -0.0555   0.0086   0.0203   0.0239   0.0265
```

```
          CORRELATION MATRIX:
A        1.0000   0.8870   0.5283   0.0564  -0.1078  -0.2046
B        0.8870   1.0000   0.2060  -0.3742  -0.5251  -0.6069
Z( 1)    0.5283   0.2060   1.0000   0.6380   0.5312   0.4623
Z( 2)    0.0564  -0.3742   0.6380   1.0000   0.9540   0.9176
Z( 3)   -0.1078  -0.5251   0.5312   0.9540   1.0000   0.9757
Z( 4)   -0.2046  -0.6069   0.4623   0.9176   0.9757   1.0000
```

          AREA = 0.9151   STD. DEV.(AREA) = 0.0197

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.0035	(0.0000 ,	0.1705)
0.010	0.0188	(0.0002 ,	0.2774)
0.020	0.0795	(0.0042 ,	0.4267)
0.030	0.1629	(0.0203 ,	0.5328)
0.040	0.2539	(0.0531 ,	0.6145)
0.050	0.3439	(0.1018 ,	0.6801)
0.060	0.4286	(0.1624 ,	0.7339)
0.070	0.5058	(0.2299 ,	0.7789)
0.080	0.5748	(0.2996 ,	0.8167)
0.090	0.6357	(0.3681 ,	0.8487)
0.100	0.6890	(0.4330 ,	0.8759)
0.110	0.7351	(0.4930 ,	0.8988)
0.120	0.7750	(0.5474 ,	0.9180)
0.130	0.8092	(0.5961 ,	0.9341)
0.140	0.8386	(0.6394 ,	0.9474)
0.150	0.8636	(0.6777 ,	0.9584)
0.200	0.9426	(0.8115 ,	0.9884)
0.250	0.9766	(0.8851 ,	0.9972)
0.300	0.9908	(0.9281 ,	0.9994)

```
0.400   0.9988      (   0.9711  ,   1.0000   )
0.500   0.9999      (   0.9887  ,   1.0000   )
0.600   1.0000      (   0.9960  ,   1.0000   )
0.700   1.0000      (   0.9988  ,   1.0000   )
0.800   1.0000      (   0.9998  ,   1.0000   )
0.900   1.0000      (   1.0000  ,   1.0000   )
0.950   1.0000      (   1.0000  ,   1.0000   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0563, 0.3986)	(0.0283, 0.1485)	(0.1026, 0.7016)
(0.0688, 0.4972)	(0.0376, 0.2320)	(0.1170, 0.7636)
(0.0905, 0.6387)	(0.0544, 0.3825)	(0.1418, 0.8434)
(0.2220, 0.9611)	(0.1612, 0.8872)	(0.2941, 0.9897)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
          F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 5, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   27.

RESPONSE DATA:
 CATEGORY   1   2   3   4   5
 ACTUALLY NEGATIVE CASES   111.   26.   4.   6.   2.
 ACTUALLY POSITIVE CASES   13.   4.   2.   3.   5.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0134 0.0537 0.0805 0.2550 1.0000
 TPF: 0.0000 0.1852 0.2963 0.3704 0.5185 1.0000

         INITIAL VALUES OF PARAMETERS:
A= 0.4690   B= 0.6101
Z(K)= 0.6584   1.4017   1.6104   2.2142
LOGL= -158.0757
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   3 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
A= 0.4488   B= 0.5997
Z(K)= 0.6599   1.3843   1.6234   2.2257
LOGL= -158.0101
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

         VARIANCE-COVARIANCE MATRIX:
A   0.1054 0.0456 0.0090 0.0031 0.0000 -0.0132

84
```

```
B        0.0456   0.0390   0.0026  -0.0041  -0.0076  -0.0227
Z( 1)    0.0090   0.0026   0.0124   0.0086   0.0077   0.0058
Z( 2)    0.0031  -0.0041   0.0086   0.0206   0.0193   0.0181
Z( 3)    0.0000  -0.0076   0.0077   0.0193   0.0273   0.0261
Z( 4)   -0.0132  -0.0227   0.0058   0.0181   0.0261   0.0689


         CORRELATION MATRIX:
A        1.0000   0.7112   0.2506   0.0663   0.0009  -0.1547
B        0.7112   1.0000   0.1173  -0.1452  -0.2333  -0.4373
Z( 1)    0.2506   0.1173   1.0000   0.5374   0.4195   0.1978
Z( 2)    0.0663  -0.1452   0.5374   1.0000   0.8143   0.4807
Z( 3)    0.0009  -0.2333   0.4195   0.8143   1.0000   0.6019
Z( 4)   -0.1547  -0.4373   0.1978   0.4807   0.6019   1.0000
```

AREA = 0.6499   STD. DEV.(AREA) = 0.0947

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.1365	(0.0359 ,	0.3478)
0.010	0.1720	(0.0571 ,	0.3770)
0.020	0.2168	(0.0891 ,	0.4131)
0.030	0.2485	(0.1141 ,	0.4389)
0.040	0.2738	(0.1352 ,	0.4600)
0.050	0.2954	(0.1535 ,	0.4785)
0.060	0.3143	(0.1697 ,	0.4952)
0.070	0.3313	(0.1843 ,	0.5106)
0.080	0.3468	(0.1975 ,	0.5250)
0.090	0.3612	(0.2097 ,	0.5386)
0.100	0.3746	(0.2209 ,	0.5516)
0.110	0.3871	(0.2313 ,	0.5640)
0.120	0.3990	(0.2410 ,	0.5759)
0.130	0.4103	(0.2501 ,	0.5874)
0.140	0.4211	(0.2586 ,	0.5986)
0.150	0.4314	(0.2667 ,	0.6093)
0.200	0.4778	(0.3013 ,	0.6588)
0.250	0.5178	(0.3292 ,	0.7023)
0.300	0.5535	(0.3528 ,	0.7411)
0.400	0.6168	(0.3922 ,	0.8073)
0.500	0.6732	(0.4256 ,	0.8611)
0.600	0.7259	(0.4567 ,	0.9049)
0.700	0.7773	(0.4879 ,	0.9402)
0.800	0.8298	(0.5222 ,	0.9679)
0.900	0.8883	(0.5669 ,	0.9883)
0.950	0.9244	(0.6017 ,	0.9955)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0130, 0.1878)	(0.0031, 0.1162)	(0.0435, 0.2818)

```
 (0.0523, 0.2999)          (0.0258, 0.2362)        (0.0968, 0.3705)
 (0.0831, 0.3515)          (0.0479, 0.2911)        (0.1351, 0.4159)
 (0.2547, 0.5212)          (0.1900, 0.4691)        (0.3292, 0.5729)
```
1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
       O F   A   B I N O R M A L   R O C   C U R V E
             F R O M   R A T I N G   D A T A

  DATA DESCRIPTION: Reader 5, Benign or Malignant

  DATA COLLECTED IN 5 CATEGORIES
  WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

  NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES = 150.

  RESPONSE DATA:
   CATEGORY   1   2   3   4   5
   ACTUALLY NEGATIVE CASES   83.   47.   14.   5.   0.
   ACTUALLY POSITIVE CASES   12.   51.   17.   44.   26.

  OBSERVED OPERATING POINTS:
   FPF: 0.0000 0.0000 0.0336 0.1275 0.4430 1.0000
   TPF: 0.0000 0.1733 0.4667 0.5800 0.9200 1.0000

          INITIAL VALUES OF PARAMETERS:
  A= 1.4291   B= 0.8815
  Z(K)= 0.1432   1.1383   1.8313   2.7112
  LOGL= -384.7947
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

  PROCEDURE CONVERGES AFTER 4 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
  A= 1.4421   B= 0.9120
  Z(K)= 0.1247   1.2686   1.6829   2.6384
  LOGL= -378.6452
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

          VARIANCE-COVARIANCE MATRIX:
  A   0.0313   0.0148   0.0098   0.0061   0.0023 -0.0103
  B   0.0148   0.0167   0.0034 -0.0058 -0.0116 -0.0288
  Z(1)   0.0098   0.0034   0.0105   0.0058   0.0044   0.0010
  Z(2)   0.0061 -0.0058   0.0058   0.0165   0.0175   0.0226
  Z(3)   0.0023 -0.0116   0.0044   0.0175   0.0255   0.0356
  Z(4) -0.0103 -0.0288   0.0010   0.0226   0.0356   0.0777

          CORRELATION MATRIX:
  A   1.0000   0.6487   0.5393   0.2689   0.0797 -0.2097
  B   0.6487   1.0000   0.2560 -0.3462 -0.5634 -0.7976
  Z(1)   0.5393   0.2560   1.0000   0.4366   0.2684   0.0361
  Z(2)   0.2689 -0.3462   0.4366   1.0000   0.8534   0.6315
  Z(3)   0.0797 -0.5634   0.2684   0.8534   1.0000   0.7996
  Z(4) -0.2097 -0.7976   0.0361   0.6315   0.7996   1.0000

       AREA = 0.8567   STD. DEV.(AREA) = 0.0228
1
  ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
  BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
  TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1821 | ( 0.0792 , | 0.3429 ) |
| 0.010 | 0.2483 | ( 0.1292 , | 0.4092 ) |
| 0.020 | 0.3331 | ( 0.2039 , | 0.4861 ) |
| 0.030 | 0.3922 | ( 0.2616 , | 0.5364 ) |
| 0.040 | 0.4384 | ( 0.3093 , | 0.5746 ) |
| 0.050 | 0.4767 | ( 0.3502 , | 0.6057 ) |
| 0.060 | 0.5095 | ( 0.3860 , | 0.6321 ) |
| 0.070 | 0.5382 | ( 0.4179 , | 0.6551 ) |
| 0.080 | 0.5637 | ( 0.4466 , | 0.6755 ) |
| 0.090 | 0.5867 | ( 0.4726 , | 0.6939 ) |
| 0.100 | 0.6076 | ( 0.4964 , | 0.7107 ) |
| 0.110 | 0.6268 | ( 0.5183 , | 0.7261 ) |
| 0.120 | 0.6445 | ( 0.5385 , | 0.7403 ) |
| 0.130 | 0.6608 | ( 0.5572 , | 0.7535 ) |
| 0.140 | 0.6761 | ( 0.5747 , | 0.7658 ) |
| 0.150 | 0.6904 | ( 0.5911 , | 0.7774 ) |
| 0.200 | 0.7501 | ( 0.6593 , | 0.8261 ) |
| 0.250 | 0.7960 | ( 0.7115 , | 0.8636 ) |
| 0.300 | 0.8325 | ( 0.7532 , | 0.8932 ) |
| 0.400 | 0.8871 | ( 0.8166 , | 0.9358 ) |
| 0.500 | 0.9254 | ( 0.8633 , | 0.9632 ) |
| 0.600 | 0.9528 | ( 0.9000 , | 0.9805 ) |
| 0.700 | 0.9726 | ( 0.9300 , | 0.9910 ) |
| 0.800 | 0.9864 | ( 0.9552 , | 0.9967 ) |
| 0.900 | 0.9955 | ( 0.9773 , | 0.9994 ) |
| 0.950 | 0.9984 | ( 0.9877 , | 0.9999 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0042, 0.1675) | (0.0007, 0.0718) | (0.0182, 0.3207) |
| (0.0462, 0.4631) | (0.0230, 0.3527) | (0.0853, 0.5763) |
| (0.1023, 0.6122) | (0.0642, 0.5221) | (0.1546, 0.6967) |
| (0.4504, 0.9080) | (0.3723, 0.8739) | (0.5305, 0.9347) |

# APPENDIX IV

## B V

R O C F I T (JUNE 1993 VERSION) :

MAXIMUM  LIKELIHOOD  ESTIMATION
OF  A  BINORMAL  ROC  CURVE
FROM  RATING  DATA


DATA DESCRIPTION: Reader 6, Mass Question

DATA COLLECTED IN  5 CATEGORIES
WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT⌐

NO. OF ACTUALLY NEGATIVE CASES =  149.      NO. OF ACTUALLY POSITIVE CASES =   59.

RESPONSE DATA:
| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 51. | 88. | 6. | 2. | 2. |
| ACTUALLY POSITIVE CASES | 4. | 6. | 8. | 13. | 28. |

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0134 0.0268 0.0671 0.6577 1.0000
 TPF: 0.0000 0.4746 0.6949 0.8305 0.9322 1.0000

          INITIAL VALUES OF PARAMETERS:
A= 1.3876    B= 0.5072
Z(K)= -0.4058     1.4979     1.9297     2.2142
LOGL= -231.0280
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE ⌐


PROCEDURE CONVERGES AFTER  9 ITERATIONS.


          FINAL VALUES OF PARAMETERS:
A= 1.5292    B= 0.5732
Z(K)= -0.3860     1.3887     1.9468     2.6902
LOGL= -223.1701
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE ⌐


          VARIANCE-COVARIANCE MATRIX:
| | | | | | |
|---|---|---|---|---|---|
| A | 0.0608 | 0.0217 | 0.0050 | 0.0064 | 0.0019 | -0.0134 |
| B | 0.0217 | 0.0157 | 0.0018 | -0.0021 | -0.0091 | -0.0270 |
| Z( 1) | 0.0050 | 0.0018 | 0.0111 | 0.0037 | 0.0025 | 0.0006 |
| Z( 2) | 0.0064 | -0.0021 | 0.0037 | 0.0207 | 0.0189 | 0.0202 |
| Z( 3) | 0.0019 | -0.0091 | 0.0025 | 0.0189 | 0.0394 | 0.0462 |
| Z( 4) | -0.0134 | -0.0270 | 0.0006 | 0.0202 | 0.0462 | 0.1115 |


          CORRELATION MATRIX:
| | | | | | |
|---|---|---|---|---|---|
| A | 1.0000 | 0.7016 | 0.1930 | 0.1810 | 0.0391 | -0.1623 |
| B | 0.7016 | 1.0000 | 0.1340 | -0.1160 | -0.3673 | -0.6461 |
| Z( 1) | 0.1930 | 0.1340 | 1.0000 | 0.2411 | 0.1213 | 0.0172 |
| Z( 2) | 0.1810 | -0.1160 | 0.2411 | 1.0000 | 0.6625 | 0.4205 |
| Z( 3) | 0.0391 | -0.3673 | 0.1213 | 0.6625 | 1.0000 | 0.6968 |
| Z( 4) | -0.1623 | -0.6461 | 0.0172 | 0.4205 | 0.6968 | 1.0000 |


     AREA =  0.9077      STD. DEV.(AREA) =  0.0284

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

```
      FPF       TPF       (LOWER BOUND, UPPER BOUND)

     0.005     0.5209     (    0.3446  ,    0.6932   )
     0.010     0.5775     (    0.4129  ,    0.7293   )
     0.020     0.6375     (    0.4879  ,    0.7684   )
     0.030     0.6739     (    0.5339  ,    0.7929   )
     0.040     0.7004     (    0.5672  ,    0.8110   )
     0.050     0.7211     (    0.5932  ,    0.8255   )
     0.060     0.7382     (    0.6144  ,    0.8376   )
     0.070     0.7527     (    0.6323  ,    0.8481   )
     0.080     0.7654     (    0.6477  ,    0.8572   )
     0.090     0.7765     (    0.6613  ,    0.8654   )
     0.100     0.7865     (    0.6734  ,    0.8728   )
     0.110     0.7956     (    0.6842  ,    0.8795   )
     0.120     0.8039     (    0.6941  ,    0.8856   )
     0.130     0.8115     (    0.7032  ,    0.8913   )
     0.140     0.8186     (    0.7115  ,    0.8965   )
     0.150     0.8251     (    0.7192  ,    0.9014   )
     0.200     0.8524     (    0.7511  ,    0.9216   )
     0.250     0.8734     (    0.7755  ,    0.9368   )
     0.300     0.8904     (    0.7954  ,    0.9487   )
     0.400     0.9168     (    0.8270  ,    0.9661   )
     0.500     0.9369     (    0.8522  ,    0.9779   )
     0.600     0.9529     (    0.8740  ,    0.9862   )
     0.700     0.9663     (    0.8941  ,    0.9920   )
     0.800     0.9779     (    0.9141  ,    0.9961   )
     0.900     0.9882     (    0.9364  ,    0.9987   )
     0.950     0.9933     (    0.9509  ,    0.9995   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT           LOWER BOUND                UPPER BOUND
   ( FPF ,    TPF )              ( FPF ,    TPF )           ( FPF ,    TPF )

 (0.0036, 0.4949)              (0.0004, 0.3490)           (0.0209, 0.6414)
 (0.0258, 0.6603)              (0.0098, 0.5755)           (0.0596, 0.7376)
 (0.0825, 0.7683)              (0.0474, 0.7161)           (0.1343, 0.8146)
 (0.6503, 0.9600)              (0.5713, 0.9487)           (0.7232, 0.9692)
1                              R O C F I T (JUNE 1993 VERSION) :
```

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
     O F   A   B I N O R M A L   R O C   C U R V E
          F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 6, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   82.

RESPONSE DATA:
```
 CATEGORY                        1       2       3       4       5
 ACTUALLY NEGATIVE CASES        46.     87.     8.      5.      3.
 ACTUALLY POSITIVE CASES         6.     11.     5.     14.     46.
```

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0201 0.0537 0.1074 0.6913 1.0000

TPF: 0.0000 0.5610 0.7317 0.7927 0.9268 1.0000

          INITIAL VALUES OF PARAMETERS:
A= 1.2746   B= 0.4676
Z(K)= -0.4991   1.2407   1.6104   2.0514
LOGL= -260.5021
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER   5 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
A= 1.3109   B= 0.4987
Z(K)= -0.4857   1.1876   1.5601   2.2769
LOGL= -257.8493
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

          VARIANCE-COVARIANCE MATRIX:
A   0.0341   0.0109   0.0044   0.0046   0.0036 -0.0012
B   0.0109   0.0093   0.0017 -0.0015 -0.0040 -0.0132
Z(1)   0.0044   0.0017   0.0114   0.0038   0.0030   0.0012
Z(2)   0.0046 -0.0015   0.0038   0.0168   0.0154   0.0153
Z(3)   0.0036 -0.0040   0.0030   0.0154   0.0239   0.0250
Z(4) -0.0012 -0.0132   0.0012   0.0153   0.0250   0.0613

          CORRELATION MATRIX:
A   1.0000   0.6111   0.2221   0.1916   0.1275 -0.0269
B   0.6111   1.0000   0.1647 -0.1178 -0.2656 -0.5533
Z(1)   0.2221   0.1647   1.0000   0.2735   0.1818   0.0462
Z(2)   0.1916 -0.1178   0.2735   1.0000   0.7662   0.4750
Z(3)   0.1275 -0.2656   0.1818   0.7662   1.0000   0.6528
Z(4) -0.0269 -0.5533   0.0462   0.4750   0.6528   1.0000

     AREA =   0.8796   STD. DEV.(AREA) =   0.0285
1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

    FPF   TPF   (LOWER BOUND, UPPER BOUND)

    0.005   0.5104   (0.3577   ,   0.6616   )
    0.010   0.5598   (0.4169   ,   0.6953   )
    0.020   0.6127   (0.4819   ,   0.7318   )
    0.030   0.6453   (0.5224   ,   0.7547   )
    0.040   0.6692   (0.5520   ,   0.7717   )
    0.050   0.6881   (0.5754   ,   0.7855   )
    0.060   0.7038   (0.5947   ,   0.7970   )
    0.070   0.7173   (0.6112   ,   0.8071   )
    0.080   0.7291   (0.6255   ,   0.8160   )
    0.090   0.7396   (0.6382   ,   0.8240   )
    0.100   0.7491   (0.6496   ,   0.8313   )
    0.110   0.7578   (0.6599   ,   0.8379   )
    0.120   0.7657   (0.6694   ,   0.8441   )
    0.130   0.7731   (0.6781   ,   0.8499   )
    0.140   0.7800   (0.6861   ,   0.8553   )
    0.150   0.7864   (0.6936   ,   0.8603   )
    0.200   0.8136   (0.7250   ,   0.8819   )
    0.250   0.8351   (0.7495   ,   0.8991   )
    0.300   0.8530   (0.7697   ,   0.9133   )

```
         0.400      0.8819      (    0.8022  ,     0.9357   )
         0.500      0.9051      (    0.8286  ,     0.9528   )
         0.600      0.9246      (    0.8517  ,     0.9664   )
         0.700      0.9421      (    0.8733  ,     0.9774   )
         0.800      0.9582      (    0.8951  ,     0.9863   )
         0.900      0.9744      (    0.9200  ,     0.9937   )
         0.950      0.9835      (    0.9366  ,     0.9969   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:


```
EXPECTED OPERATING POINT          LOWER BOUND              UPPER BOUND
   ( FPF ,   TPF )               ( FPF ,   TPF )          ( FPF ,   TPF )

  (0.0114, 0.5696)              (0.0029, 0.4735)        (0.0366, 0.6618)
  (0.0594, 0.7029)              (0.0312, 0.6487)        (0.1043, 0.7530)
  (0.1175, 0.7638)              (0.0747, 0.7230)        (0.1753, 0.8011)
  (0.6864, 0.9398)              (0.6088, 0.9263)        (0.7565, 0.9513)
1                           R O C F I T (JUNE 1993 VERSION) :
```

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 6, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   27.

```
RESPONSE DATA:
 CATEGORY                      1      2      3      4      5
 ACTUALLY NEGATIVE CASES      42.    87.    7.    12.    1.
 ACTUALLY POSITIVE CASES       2.     9.    5.     7.    4.
```

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0067 0.0872 0.1342 0.7181 1.0000
 TPF: 0.0000 0.1481 0.4074 0.5926 0.9259 1.0000

         INITIAL VALUES OF PARAMETERS:
A= 0.9964   B= 0.8218
Z(K)= −0.5769   1.1067   1.3581   2.4728
LOGL= −198.7468
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
A= 1.0463   B= 0.8553
Z(K)= −0.5722   1.0813   1.4054   2.4435
LOGL= −198.2965
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

         VARIANCE−COVARIANCE MATRIX:
A   0.0833 0.0310 0.0072 0.0082 0.0068 −0.0055
```

```
B         0.0310   0.0312   0.0029  -0.0019  -0.0051  -0.0270
Z( 1)     0.0072   0.0029   0.0118   0.0037   0.0031   0.0008
Z( 2)     0.0082  -0.0019   0.0037   0.0156   0.0140   0.0129
Z( 3)     0.0068  -0.0051   0.0031   0.0140   0.0207   0.0199
Z( 4)    -0.0055  -0.0270   0.0008   0.0129   0.0199   0.0889


          CORRELATION MATRIX:
A         1.0000   0.6084   0.2307   0.2287   0.1637  -0.0639
B         0.6084   1.0000   0.1536  -0.0877  -0.2004  -0.5135
Z( 1)     0.2307   0.1536   1.0000   0.2763   0.1981   0.0251
Z( 2)     0.2287  -0.0877   0.2763   1.0000   0.7777   0.3453
Z( 3)     0.1637  -0.2004   0.1981   0.7777   1.0000   0.4639
Z( 4)    -0.0639  -0.5135   0.0251   0.3453   0.4639   1.0000
```

AREA =   0.7867   STD. DEV.(AREA) =   0.0540

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.1236	(0.0311 ,	0.3266)
0.010	0.1726	(0.0562 ,	0.3819)
0.020	0.2386	(0.0985 ,	0.4479)
0.030	0.2868	(0.1343 ,	0.4924)
0.040	0.3258	(0.1657 ,	0.5272)
0.050	0.3591	(0.1940 ,	0.5562)
0.060	0.3883	(0.2198 ,	0.5813)
0.070	0.4144	(0.2435 ,	0.6036)
0.080	0.4381	(0.2655 ,	0.6237)
0.090	0.4599	(0.2859 ,	0.6421)
0.100	0.4801	(0.3051 ,	0.6590)
0.110	0.4988	(0.3231 ,	0.6748)
0.120	0.5164	(0.3401 ,	0.6895)
0.130	0.5330	(0.3563 ,	0.7034)
0.140	0.5487	(0.3716 ,	0.7164)
0.150	0.5635	(0.3861 ,	0.7288)
0.200	0.6280	(0.4501 ,	0.7819)
0.250	0.6807	(0.5029 ,	0.8244)
0.300	0.7251	(0.5479 ,	0.8590)
0.400	0.7967	(0.6228 ,	0.9110)
0.500	0.8523	(0.6846 ,	0.9465)
0.600	0.8966	(0.7388 ,	0.9703)
0.700	0.9325	(0.7891 ,	0.9856)
0.800	0.9613	(0.8384 ,	0.9945)
0.900	0.9839	(0.8917 ,	0.9989)
0.950	0.9929	(0.9244 ,	0.9997)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0073, 0.1483)	(0.0012, 0.0613)	(0.0315, 0.2933)

```
    (0.0800, 0.4381)          (0.0458, 0.3457)        (0.1306, 0.5340)
    (0.1398, 0.5483)          (0.0924, 0.4650)        (0.2014, 0.6296)
    (0.7164, 0.9377)          (0.6402, 0.9120)        (0.7839, 0.9571)
```

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
O F   A   B I N O R M A L   R O C   C U R V E
F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 6, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES = 150.

RESPONSE DATA:
```
 CATEGORY                      1      2      3      4      5
 ACTUALLY NEGATIVE CASES     10.   121.   17.    1.    0.
 ACTUALLY POSITIVE CASES      1.    31.   71.   32.   15.
```

OBSERVED OPERATING POINTS:
```
 FPF: 0.0000 0.0000 0.0067 0.1208 0.9329 1.0000
 TPF: 0.0000 0.1000 0.3133 0.7867 0.9933 1.0000
```

          INITIAL VALUES OF PARAMETERS:
```
A= 1.3830     B= 0.8297
Z(K)= -1.4979     1.1711     2.4728     2.7112
LOGL= -313.1151
```
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   7 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
```
A= 1.6109     B= 0.7475
Z(K)= -1.4729     1.1370     2.7862     3.8593
LOGL= -285.8086
```
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

          VARIANCE-COVARIANCE MATRIX:
```
A       0.0461   0.0232   0.0070   0.0102  -0.0279  -0.0598
B       0.0232   0.0210   0.0041  -0.0013  -0.0444  -0.0753
Z( 1)   0.0070   0.0041   0.0238   0.0026  -0.0055  -0.0113
Z( 2)   0.0102  -0.0013   0.0026   0.0165   0.0181   0.0200
Z( 3)  -0.0279  -0.0444  -0.0055   0.0181   0.1331   0.1946
Z( 4)  -0.0598  -0.0753  -0.0113   0.0200   0.1946   0.3304
```


          CORRELATION MATRIX:
```
A       1.0000   0.7445   0.2125   0.3717  -0.3564  -0.4846
B       0.7445   1.0000   0.1815  -0.0677  -0.8396  -0.9048
Z( 1)   0.2125   0.1815   1.0000   0.1322  -0.0969  -0.1278
Z( 2)   0.3717  -0.0677   0.1322   1.0000   0.3857   0.2706
Z( 3)  -0.3564  -0.8396  -0.0969   0.3857   1.0000   0.9278
Z( 4)  -0.4846  -0.9048  -0.1278   0.2706   0.9278   1.0000
```


       AREA = 0.9015   STD. DEV.(AREA) = 0.0210
1

  ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
  BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
  TRUE-POSITIVE FRACTION AT EACH SPECIFIED

FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.3764	(0.2065 ,	0.5748)
0.010	0.4489	(0.2827 ,	0.6248)
0.020	0.5300	(0.3767 ,	0.6790)
0.030	0.5811	(0.4394 ,	0.7129)
0.040	0.6187	(0.4865 ,	0.7382)
0.050	0.6484	(0.5243 ,	0.7585)
0.060	0.6731	(0.5555 ,	0.7756)
0.070	0.6941	(0.5821 ,	0.7904)
0.080	0.7124	(0.6051 ,	0.8035)
0.090	0.7286	(0.6254 ,	0.8153)
0.100	0.7431	(0.6433 ,	0.8260)
0.110	0.7561	(0.6594 ,	0.8357)
0.120	0.7681	(0.6739 ,	0.8448)
0.130	0.7790	(0.6872 ,	0.8531)
0.140	0.7891	(0.6993 ,	0.8609)
0.150	0.7985	(0.7104 ,	0.8682)
0.200	0.8369	(0.7553 ,	0.8984)
0.250	0.8658	(0.7883 ,	0.9212)
0.300	0.8886	(0.8142 ,	0.9388)
0.400	0.9225	(0.8534 ,	0.9635)
0.500	0.9464	(0.8830 ,	0.9789)
0.600	0.9641	(0.9071 ,	0.9886)
0.700	0.9774	(0.9281 ,	0.9945)
0.800	0.9875	(0.9474 ,	0.9979)
0.900	0.9949	(0.9668 ,	0.9995)
0.950	0.9977	(0.9779 ,	0.9999)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0001, 0.1013)	(0.0000, 0.0172)	(0.0031, 0.3330)
(0.0027, 0.3185)	(0.0002, 0.1571)	(0.0192, 0.5250)
(0.1278, 0.7767)	(0.0825, 0.7166)	(0.1880, 0.8287)
(0.9296, 0.9967)	(0.8791, 0.9935)	(0.9621, 0.9983)

APPENDIX IV

B VI

ROCFIT (JUNE 1993 VERSION) :

MAXIMUM LIKELIHOOD ESTIMATION
OF A BINORMAL ROC CURVE
FROM RATING DATA

DATA DESCRIPTION: Reader 7, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   59.

RESPONSE DATA:

CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	82.	51.	8.	6.	2.
ACTUALLY POSITIVE CASES	1.	8.	4.	9.	37.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0134 0.0537 0.1074 0.4497 1.0000
 TPF: 0.0000 0.6271 0.7797 0.8475 0.9831 1.0000

INITIAL VALUES OF PARAMETERS:
A= 2.1865   B= 0.8676
Z(K)= 0.1262   1.2407   1.6104   2.2142
LOGL= -220.2996
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 2.1233   B= 0.8333
Z(K)= 0.1238   1.2597   1.6061   2.1666
LOGL= -220.1214
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

A	0.1270	0.0611	0.0083	0.0099	0.0041	-0.0168
B	0.0611	0.0430	0.0026	-0.0018	-0.0086	-0.0286
Z(1)	0.0083	0.0026	0.0106	0.0055	0.0046	0.0032
Z(2)	0.0099	-0.0018	0.0055	0.0180	0.0165	0.0161
Z(3)	0.0041	-0.0086	0.0046	0.0165	0.0253	0.0269
Z(4)	-0.0168	-0.0286	0.0032	0.0161	0.0269	0.0560

CORRELATION MATRIX:

A	1.0000	0.8274	0.2270	0.2065	0.0715	-0.1987
B	0.8274	1.0000	0.1239	-0.0647	-0.2618	-0.5828
Z(1)	0.2270	0.1239	1.0000	0.4000	0.2837	0.1313
Z(2)	0.2065	-0.0647	0.4000	1.0000	0.7723	0.5057
Z(3)	0.0715	-0.2618	0.2837	0.7723	1.0000	0.7138
Z(4)	-0.1987	-0.5828	0.1313	0.5057	0.7138	1.0000

AREA = 0.9486   STD. DEV.(AREA) = 0.0174

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

```
       FPF        TPF        (LOWER BOUND,  UPPER BOUND)

      0.005      0.4907      (   0.2628  ,    0.7217   )
      0.010      0.5732      (   0.3620  ,    0.7648   )
      0.020      0.6597      (   0.4772  ,    0.8107   )
      0.030      0.7108      (   0.5483  ,    0.8389   )
      0.040      0.7467      (   0.5986  ,    0.8596   )
      0.050      0.7741      (   0.6367  ,    0.8759   )
      0.060      0.7960      (   0.6669  ,    0.8894   )
      0.070      0.8142      (   0.6916  ,    0.9008   )
      0.080      0.8295      (   0.7122  ,    0.9106   )
      0.090      0.8428      (   0.7298  ,    0.9192   )
      0.100      0.8543      (   0.7450  ,    0.9267   )
      0.110      0.8646      (   0.7583  ,    0.9334   )
      0.120      0.8737      (   0.7701  ,    0.9393   )
      0.130      0.8819      (   0.7806  ,    0.9446   )
      0.140      0.8893      (   0.7901  ,    0.9494   )
      0.150      0.8961      (   0.7987  ,    0.9537   )
      0.200      0.9225      (   0.8325  ,    0.9699   )
      0.250      0.9408      (   0.8566  ,    0.9802   )
      0.300      0.9542      (   0.8751  ,    0.9869   )
      0.400      0.9721      (   0.9026  ,    0.9943   )
      0.500      0.9831      (   0.9229  ,    0.9976   )
      0.600      0.9902      (   0.9392  ,    0.9991   )
      0.700      0.9948      (   0.9532  ,    0.9997   )
      0.800      0.9976      (   0.9660  ,    0.9999   )
      0.900      0.9993      (   0.9785  ,    1.0000   )
      0.950      0.9998      (   0.9856  ,    1.0000   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0151, 0.6247)	(0.0043, 0.4726)	(0.0443, 0.7594)
(0.0541, 0.7837)	(0.0275, 0.7002)	(0.0978, 0.8520)
(0.1039, 0.8585)	(0.0639, 0.8035)	(0.1595, 0.9020)
(0.4507, 0.9783)	(0.3725, 0.9680)	(0.5310, 0.9857)

```
1                          R O C F I T (JUNE 1993 VERSION) :

   M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
       O F   A   B I N O R M A L   R O C   C U R V E
              F R O M   R A T I N G   D A T A
```

DATA DESCRIPTION: Reader 7, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   82.

RESPONSE DATA:

CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	98.	39.	2.	5.	5.
ACTUALLY POSITIVE CASES	5.	7.	0.	8.	62.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0336 0.0671 0.0805 0.3423 1.0000

TPF: 0.0000 0.7561 0.8537 0.8537 0.9390 1.0000

                INITIAL VALUES OF PARAMETERS:
A= 1.8145   B= 0.5476
Z(K)= 0.4058   1.4017   1.4979   1.8313
LOGL= -205.7691
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

                FINAL VALUES OF PARAMETERS:
A= 1.8307   B= 0.5978
Z(K)= 0.4095   1.3735   1.4355   1.8921
LOGL= -204.5984
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

                VARIANCE-COVARIANCE MATRIX:
A   0.0774   0.0364   0.0075   0.0040   0.0032 -0.0060
B   0.0364   0.0270   0.0024 -0.0042 -0.0051 -0.0154
Z(1)   0.0075   0.0024   0.0112   0.0067   0.0065   0.0051
Z(2)   0.0040 -0.0042   0.0067   0.0202   0.0199   0.0195
Z(3)   0.0032 -0.0051   0.0065   0.0199   0.0215   0.0212
Z(4)   -0.0060 -0.0154   0.0051   0.0195   0.0212   0.0394

                CORRELATION MATRIX:
A   1.0000   0.7951   0.2546   0.1018   0.0795 -0.1083
B   0.7951   1.0000   0.1361 -0.1777 -0.2116 -0.4724
Z(1)   0.2546   0.1361   1.0000   0.4468   0.4199   0.2418
Z(2)   0.1018 -0.1777   0.4468   1.0000   0.9569   0.6916
Z(3)   0.0795 -0.2116   0.4199   0.9569   1.0000   0.7298
Z(4)   -0.1083 -0.4724   0.2418   0.6916   0.7298   1.0000

        AREA = 0.9420   STD. DEV.(AREA) = 0.0190

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

      FPF   TPF   (LOWER BOUND, UPPER BOUND)

     0.005   0.6144   (0.4107   ,   0.7902   )
     0.010   0.6700   (0.4929   ,   0.8153   )
     0.020   0.7267   (0.5796   ,   0.8425   )
     0.030   0.7600   (0.6305   ,   0.8598   )
     0.040   0.7835   (0.6658   ,   0.8728   )
     0.050   0.8016   (0.6924   ,   0.8833   )
     0.060   0.8162   (0.7135   ,   0.8923   )
     0.070   0.8285   (0.7307   ,   0.9000   )
     0.080   0.8391   (0.7452   ,   0.9069   )
     0.090   0.8483   (0.7576   ,   0.9131   )
     0.100   0.8565   (0.7683   ,   0.9186   )
     0.110   0.8638   (0.7778   ,   0.9237   )
     0.120   0.8704   (0.7862   ,   0.9283   )
     0.130   0.8764   (0.7937   ,   0.9326   )
     0.140   0.8820   (0.8005   ,   0.9365   )
     0.150   0.8871   (0.8067   ,   0.9402   )
     0.200   0.9079   (0.8313   ,   0.9551   )
     0.250   0.9233   (0.8491   ,   0.9658   )
     0.300   0.9354   (0.8630   ,   0.9739   )

```
0.400    0.9535    (   0.8843  ,   0.9847   )
0.500    0.9664    (   0.9007  ,   0.9912   )
0.600    0.9763    (   0.9147  ,   0.9953   )
0.700    0.9840    (   0.9274  ,   0.9977   )
0.800    0.9902    (   0.9401  ,   0.9991   )
0.900    0.9953    (   0.9543  ,   0.9998   )
0.950    0.9976    (   0.9637  ,   0.9999   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0292, 0.7580)	(0.0113, 0.6798)	(0.0664, 0.8244)
(0.0756, 0.8346)	(0.0425, 0.7884)	(0.1255, 0.8738)
(0.0848, 0.8437)	(0.0493, 0.8005)	(0.1368, 0.8802)
(0.3411, 0.9436)	(0.2687, 0.9281)	(0.4199, 0.9564)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
        F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 7, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES =   27.

RESPONSE DATA:
 CATEGORY   1   2   3   4   5
 ACTUALLY NEGATIVE CASES   87.   40.   6.   12.   4.
 ACTUALLY POSITIVE CASES   5.   7.   1.   8.   6.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0268 0.1074 0.1477 0.4161 1.0000
 TPF: 0.0000 0.2222 0.5185 0.5556 0.8148 1.0000

        INITIAL VALUES OF PARAMETERS:
A= 1.1369   B= 0.9553
Z(K)= 0.2115   1.0466   1.2407   1.9297
LOGL= -203.8137
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

        FINAL VALUES OF PARAMETERS:
A= 1.1181   B= 0.9444
Z(K)= 0.2135   1.0427   1.2129   1.9635
LOGL= -203.6756
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

        VARIANCE-COVARIANCE MATRIX:
A   0.1028 0.0501 0.0105 0.0077 0.0063 -0.0052
```

100

```
B        0.0501   0.0503   0.0036  -0.0028  -0.0051  -0.0218
Z( 1)    0.0105   0.0036   0.0107   0.0066   0.0061   0.0040
Z( 2)    0.0077  -0.0028   0.0066   0.0149   0.0140   0.0123
Z( 3)    0.0063  -0.0051   0.0061   0.0140   0.0171   0.0154
Z( 4)   -0.0052  -0.0218   0.0040   0.0123   0.0154   0.0438


         CORRELATION MATRIX:
A        1.0000   0.6973   0.3172   0.1970   0.1497  -0.0771
B        0.6973   1.0000   0.1548  -0.1016  -0.1732  -0.4642
Z( 1)    0.3172   0.1548   1.0000   0.5240   0.4478   0.1836
Z( 2)    0.1970  -0.1016   0.5240   1.0000   0.8780   0.4818
Z( 3)    0.1497  -0.1732   0.4478   0.8780   1.0000   0.5624
Z( 4)   -0.0771  -0.4642   0.1836   0.4818   0.5624   1.0000


      AREA =  0.7919        STD. DEV.(AREA) =  0.0521
```

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.0943	(0.0161 ,	0.3129)
0.010	0.1402	(0.0346 ,	0.3663)
0.020	0.2056	(0.0709 ,	0.4306)
0.030	0.2551	(0.1050 ,	0.4746)
0.040	0.2961	(0.1368 ,	0.5094)
0.050	0.3316	(0.1664 ,	0.5388)
0.060	0.3630	(0.1940 ,	0.5645)
0.070	0.3913	(0.2197 ,	0.5876)
0.080	0.4172	(0.2439 ,	0.6087)
0.090	0.4411	(0.2665 ,	0.6281)
0.100	0.4632	(0.2878 ,	0.6462)
0.110	0.4839	(0.3078 ,	0.6632)
0.120	0.5033	(0.3268 ,	0.6793)
0.130	0.5217	(0.3447 ,	0.6944)
0.140	0.5390	(0.3616 ,	0.7088)
0.150	0.5554	(0.3777 ,	0.7225)
0.200	0.6268	(0.4474 ,	0.7821)
0.250	0.6849	(0.5036 ,	0.8299)
0.300	0.7334	(0.5506 ,	0.8685)
0.400	0.8104	(0.6265 ,	0.9245)
0.500	0.8682	(0.6878 ,	0.9596)
0.600	0.9126	(0.7410 ,	0.9807)
0.700	0.9466	(0.7901 ,	0.9922)
0.800	0.9721	(0.8384 ,	0.9977)
0.900	0.9901	(0.8907 ,	0.9997)
0.950	0.9962	(0.9231 ,	1.0000)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0248, 0.2308)	(0.0088, 0.1306)	(0.0602, 0.3636)

```
       (0.1126, 0.4891)              (0.0709, 0.3939)        (0.1694, 0.5850)
       (0.1485, 0.5531)              (0.1000, 0.4633)        (0.2108, 0.6402)
       (0.4155, 0.8203)              (0.3386, 0.7658)        (0.4957, 0.8660)
```
1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
        O F   A   B I N O R M A L   R O C   C U R V E
                F R O M   R A T I N G   D A T A

   DATA DESCRIPTION: Reader 7, Benign or Malignant

   DATA COLLECTED IN 5 CATEGORIES
   WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

   NO. OF ACTUALLY NEGATIVE CASES = 149.   NO. OF ACTUALLY POSITIVE CASES = 150.

   RESPONSE DATA:
    CATEGORY   1   2   3   4   5
    ACTUALLY NEGATIVE CASES   43.   87.   19.   0.   0.
    ACTUALLY POSITIVE CASES   2.   24.   89.   24.   11.

   OBSERVED OPERATING POINTS:
    FPF: 0.0000 0.0000 0.0000 0.1275 0.7114 1.0000
    TPF: 0.0000 0.0733 0.2333 0.8267 0.9867 1.0000

            INITIAL VALUES OF PARAMETERS:
   A= 1.8003   B= 1.0541
   Z(K)= -0.5571   1.1383   2.6112   2.7112
   LOGL= -343.1591
   CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

   PROCEDURE CONVERGES AFTER   7 ITERATIONS.

            FINAL VALUES OF PARAMETERS:
   A= 1.7862   B= 0.7355
   Z(K)= -0.5591   1.1430   3.4209   4.4039
   LOGL= -311.2273
   CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

            VARIANCE-COVARIANCE MATRIX:
   A   0.0407   0.0213   0.0064   0.0068 -0.0468 -0.0744
   B   0.0213   0.0236   0.0032 -0.0046 -0.0791 -0.1112
   Z(1)   0.0064   0.0032   0.0118   0.0036 -0.0060 -0.0102
   Z(2)   0.0068 -0.0046   0.0036   0.0168   0.0303   0.0364
   Z(3) -0.0468 -0.0791 -0.0060   0.0303   0.3152   0.4174
   Z(4) -0.0744 -0.1112 -0.0102   0.0364   0.4174   0.5974

            CORRELATION MATRIX:
   A   1.0000   0.6882   0.2914   0.2582 -0.4137 -0.4775
   B   0.6882   1.0000   0.1894 -0.2296 -0.9163 -0.9358
   Z(1)   0.2914   0.1894   1.0000   0.2550 -0.0979 -0.1216
   Z(2)   0.2582 -0.2296   0.2550   1.0000   0.4159   0.3636
   Z(3) -0.4137 -0.9163 -0.0979   0.4159   1.0000   0.9618
   Z(4) -0.4775 -0.9358 -0.1216   0.3636   0.9618   1.0000

        AREA = 0.9249   STD. DEV.(AREA) = 0.0167

1
   ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
   BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
   TRUE-POSITIVE FRACTION AT EACH SPECIFIED

FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.4568	(0.2456 ,	0.6814)
0.010	0.5299	(0.3296 ,	0.7227)
0.020	0.6085	(0.4307 ,	0.7659)
0.030	0.6564	(0.4966 ,	0.7922)
0.040	0.6909	(0.5455 ,	0.8112)
0.050	0.7178	(0.5842 ,	0.8264)
0.060	0.7397	(0.6160 ,	0.8390)
0.070	0.7582	(0.6428 ,	0.8498)
0.080	0.7742	(0.6658 ,	0.8593)
0.090	0.7882	(0.6859 ,	0.8677)
0.100	0.8006	(0.7037 ,	0.8754)
0.110	0.8117	(0.7194 ,	0.8824)
0.120	0.8217	(0.7336 ,	0.8888)
0.130	0.8309	(0.7464 ,	0.8948)
0.140	0.8393	(0.7580 ,	0.9003)
0.150	0.8471	(0.7686 ,	0.9055)
0.200	0.8785	(0.8106 ,	0.9271)
0.250	0.9015	(0.8402 ,	0.9436)
0.300	0.9194	(0.8626 ,	0.9563)
0.400	0.9452	(0.8949 ,	0.9743)
0.500	0.9630	(0.9179 ,	0.9854)
0.600	0.9757	(0.9359 ,	0.9923)
0.700	0.9851	(0.9510 ,	0.9964)
0.800	0.9919	(0.9646 ,	0.9987)
0.900	0.9968	(0.9778 ,	0.9997)
0.950	0.9986	(0.9853 ,	0.9999)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0000, 0.0732)	(0.0000, 0.0051)	(0.0019, 0.3675)
(0.0003, 0.2328)	(0.0000, 0.0619)	(0.0102, 0.5317)
(0.1265, 0.8278)	(0.0812, 0.7760)	(0.1870, 0.8713)
(0.7120, 0.9860)	(0.6355, 0.9794)	(0.7799, 0.9907)

APPENDIX IV

B VII

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
        F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 9, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL:

NO. OF ACTUALLY NEGATIVE CASES = 125.   NO. OF ACTUALLY POSITIVE CASES =   51.

RESPONSE DATA:
 CATEGORY   1   2   3   4   5
 ACTUALLY NEGATIVE CASES   87.   25.   13.   0.   0.
 ACTUALLY POSITIVE CASES   4.   6.   10.   9.   22.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0000 0.0000 0.1040 0.3040 1.0000
 TPF: 0.0000 0.4314 0.6078 0.8039 0.9216 1.0000

         INITIAL VALUES OF PARAMETERS:
A= 1.7240   B= 0.6484
Z(K)= 0.5125   1.2592   2.5525   2.6525
LOGL= -186.1320
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES AR]

PROCEDURE CONVERGES AFTER   8 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
A= 1.5837   B= 0.4840
Z(K)= 0.5062   1.3070   2.7322   3.6470
LOGL= -175.6608
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES AR]

         VARIANCE-COVARIANCE MATRIX:
A   0.0885   0.0335   0.0074   0.0054 -0.0349 -0.0885
B   0.0335   0.0230   0.0020 -0.0021 -0.0488 -0.0949
Z(1)   0.0074   0.0020   0.0138   0.0091   0.0041   0.0004
Z(2)   0.0054 -0.0021   0.0091   0.0226   0.0227   0.0268
Z(3)   -0.0349 -0.0488   0.0041   0.0227   0.2101   0.2978
Z(4)   -0.0885 -0.0949   0.0004   0.0268   0.2978   0.5556

         CORRELATION MATRIX:
A   1.0000   0.7424   0.2112   0.1205 -0.2558 -0.3991
B   0.7424   1.0000   0.1114 -0.0941 -0.7011 -0.8390
Z(1)   0.2112   0.1114   1.0000   0.5152   0.0759   0.0042
Z(2)   0.1205 -0.0941   0.5152   1.0000   0.3294   0.2388
Z(3)   -0.2558 -0.7011   0.0759   0.3294   1.0000   0.8716
Z(4)   -0.3991 -0.8390   0.0042   0.2388   0.8716   1.0000

      AREA =   0.9230   STD. DEV.(AREA) =   0.0307

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

```
        FPF       TPF       (LOWER BOUND, UPPER BOUND)

       0.005     0.6318     (   0.4299  ,    0.8024   )
       0.010     0.6763     (   0.4955  ,    0.8228   )
       0.020     0.7222     (   0.5636  ,    0.8458   )
       0.030     0.7496     (   0.6035  ,    0.8608   )
       0.040     0.7692     (   0.6315  ,    0.8721   )
       0.050     0.7845     (   0.6527  ,    0.8814   )
       0.060     0.7970     (   0.6698  ,    0.8893   )
       0.070     0.8076     (   0.6839  ,    0.8961   )
       0.080     0.8169     (   0.6959  ,    0.9022   )
       0.090     0.8250     (   0.7063  ,    0.9077   )
       0.100     0.8323     (   0.7154  ,    0.9127   )
       0.110     0.8389     (   0.7236  ,    0.9172   )
       0.120     0.8449     (   0.7309  ,    0.9214   )
       0.130     0.8505     (   0.7375  ,    0.9252   )
       0.140     0.8556     (   0.7436  ,    0.9288   )
       0.150     0.8604     (   0.7492  ,    0.9322   )
       0.200     0.8803     (   0.7719  ,    0.9460   )
       0.250     0.8957     (   0.7890  ,    0.9565   )
       0.300     0.9082     (   0.8027  ,    0.9648   )
       0.400     0.9280     (   0.8242  ,    0.9768   )
       0.500     0.9434     (   0.8415  ,    0.9849   )
       0.600     0.9560     (   0.8566  ,    0.9905   )
       0.700     0.9669     (   0.8709  ,    0.9945   )
       0.800     0.9768     (   0.8857  ,    0.9973   )
       0.900     0.9862     (   0.9034  ,    0.9991   )
       0.950     0.9913     (   0.9160  ,    0.9996   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND              UPPER BOUND
    ( FPF ,    TPF )             ( FPF ,    TPF )         ( FPF ,    TPF )

(0.0001, 0.4280)              (0.0000, 0.1871)        (0.0144, 0.7004)
(0.0031, 0.6030)              (0.0001, 0.4311)        (0.0333, 0.7568)
(0.0956, 0.8292)              (0.0546, 0.7906)        (0.1557, 0.8630)
(0.3064, 0.9097)              (0.2308, 0.8902)        (0.3912, 0.9265)
```
1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 9, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

NO. OF ACTUALLY NEGATIVE CASES = 125.   NO. OF ACTUALLY POSITIVE CASES =   65.

RESPONSE DATA:
```
 CATEGORY                      1       2       3       4       5
 ACTUALLY NEGATIVE CASES     120.     4.      0.      0.      1.
 ACTUALLY POSITIVE CASES      23.     0.      2.      5.     35.
```

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0080 0.0080 0.0080 0.0400 1.0000

TPF: 0.0000 0.5385 0.6154 0.6462 0.6462 1.0000

          INITIAL VALUES OF PARAMETERS:
A= 1.3348   B= 0.4725
Z(K)= 1.7511   2.2093   2.3093   2.4093
LOGL=   -98.6914
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI

PROCEDURE CONVERGES AFTER   8 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
A= 0.8911   B= 0.2887
Z(K)= 1.7590   2.0535   2.2508   2.7339
LOGL=   -94.1625
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI

          VARIANCE-COVARIANCE MATRIX:
A   0.1439   0.0582   0.0187 -0.0051 -0.0258 -0.0947
B   0.0582   0.0291   0.0038 -0.0093 -0.0206 -0.0582
Z(1)   0.0187   0.0038   0.0419   0.0377   0.0351   0.0291
Z(2)   -0.0051 -0.0093   0.0377   0.0578   0.0596   0.0693
Z(3)   -0.0258 -0.0206   0.0351   0.0596   0.0815   0.1048
Z(4)   -0.0947 -0.0582   0.0291   0.0693   0.1048   0.2247

          CORRELATION MATRIX:
A   1.0000   0.9004   0.2413 -0.0564 -0.2380 -0.5266
B   0.9004   1.0000   0.1084 -0.2260 -0.4226 -0.7202
Z(1)   0.2413   0.1084   1.0000   0.7662   0.6009   0.2999
Z(2)   -0.0564 -0.2260   0.7662   1.0000   0.8682   0.6084
Z(3)   -0.2380 -0.4226   0.6009   0.8682   1.0000   0.7746
Z(4)   -0.5266 -0.7202   0.2999   0.6084   0.7746   1.0000

      AREA = 0.8040   STD. DEV.(AREA) = 0.0912

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.5585	(0.4096 ,	0.6995)
0.010	0.5868	(0.4516 ,	0.7123)
0.020	0.6171	(0.4897 ,	0.7330)
0.030	0.6360	(0.5087 ,	0.7498)
0.040	0.6501	(0.5204 ,	0.7642)
0.050	0.6613	(0.5284 ,	0.7767)
0.060	0.6708	(0.5341 ,	0.7877)
0.070	0.6790	(0.5384 ,	0.7976)
0.080	0.6863	(0.5418 ,	0.8066)
0.090	0.6928	(0.5446 ,	0.8148)
0.100	0.6988	(0.5468 ,	0.8224)
0.110	0.7043	(0.5486 ,	0.8294)
0.120	0.7094	(0.5501 ,	0.8358)
0.130	0.7142	(0.5515 ,	0.8419)
0.140	0.7188	(0.5526 ,	0.8476)
0.150	0.7230	(0.5535 ,	0.8529)
0.200	0.7415	(0.5567 ,	0.8756)
0.250	0.7569	(0.5584 ,	0.8936)
0.300	0.7703	(0.5592 ,	0.9083)

```
       0.400      0.7933      (    0.5595  ,     0.9314   )
       0.500      0.8136      (    0.5587  ,     0.9489   )
       0.600      0.8325      (    0.5571  ,     0.9628   )
       0.700      0.8514      (    0.5549  ,     0.9742   )
       0.800      0.8716      (    0.5517  ,     0.9837   )
       0.900      0.8964      (    0.5465  ,     0.9919   )
       0.950      0.9140      (    0.5417  ,     0.9957   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0031, 0.5405)	(0.0001, 0.4339)	(0.0355, 0.6443)
(0.0122, 0.5953)	(0.0025, 0.5317)	(0.0454, 0.6564)
(0.0200, 0.6172)	(0.0058, 0.5644)	(0.0568, 0.6679)
(0.0393, 0.6492)	(0.0154, 0.6054)	(0.0872, 0.6911)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
         F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 9, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

NO. OF ACTUALLY NEGATIVE CASES = 125.   NO. OF ACTUALLY POSITIVE CASES =   27.

RESPONSE DATA:
```
 CATEGORY                       1      2      3      4      5
 ACTUALLY NEGATIVE CASES    110.    10.     4.     0.     1.
 ACTUALLY POSITIVE CASES     14.     2.     2.     6.     3.
```

OBSERVED OPERATING POINTS:
```
 FPF: 0.0000 0.0080 0.0080 0.0400 0.1200 1.0000
 TPF: 0.0000 0.1111 0.3333 0.4074 0.4815 1.0000
```

```
        INITIAL VALUES OF PARAMETERS:
A=  0.9060    B=  0.7267
Z(K)=  1.1751    1.7511    2.3093    2.4093
LOGL=  -104.1775
```
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   9 ITERATIONS.


```
        FINAL VALUES OF PARAMETERS:
A=  0.7393    B=  0.6325
Z(K)=  1.1833    1.6786    2.1371    2.9004
LOGL=   -96.8623
```
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


```
        VARIANCE-COVARIANCE MATRIX:
A       0.2046  0.0948  0.0185  0.0021 -0.0236 -0.1023
```

```
B        0.0948   0.0614   0.0043  -0.0083  -0.0279  -0.0864
Z( 1)    0.0185   0.0043   0.0213   0.0172   0.0144   0.0097
Z( 2)    0.0021  -0.0083   0.0172   0.0338   0.0328   0.0381
Z( 3)   -0.0236  -0.0279   0.0144   0.0328   0.0676   0.0869
Z( 4)   -0.1023  -0.0864   0.0097   0.0381   0.0869   0.2634


         CORRELATION MATRIX:
A        1.0000   0.8458   0.2800   0.0251  -0.2005  -0.4407
B        0.8458   1.0000   0.1192  -0.1824  -0.4333  -0.6794
Z( 1)    0.2800   0.1192   1.0000   0.6440   0.3785   0.1302
Z( 2)    0.0251  -0.1824   0.6440   1.0000   0.6866   0.4042
Z( 3)   -0.2005  -0.4333   0.3785   0.6866   1.0000   0.6512
Z( 4)   -0.4407  -0.6794   0.1302   0.4042   0.6512   1.0000
```

AREA = 0.7339   STD. DEV.(AREA) = 0.1068

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.1867	(0.0572 ,	0.4202)
0.010	0.2319	(0.0903 ,	0.4499)
0.020	0.2877	(0.1370 ,	0.4895)
0.030	0.3261	(0.1708 ,	0.5199)
0.040	0.3563	(0.1972 ,	0.5459)
0.050	0.3816	(0.2186 ,	0.5691)
0.060	0.4035	(0.2366 ,	0.5904)
0.070	0.4229	(0.2519 ,	0.6102)
0.080	0.4405	(0.2652 ,	0.6286)
0.090	0.4566	(0.2769 ,	0.6459)
0.100	0.4715	(0.2873 ,	0.6622)
0.110	0.4854	(0.2966 ,	0.6776)
0.120	0.4984	(0.3051 ,	0.6921)
0.130	0.5107	(0.3128 ,	0.7059)
0.140	0.5223	(0.3199 ,	0.7190)
0.150	0.5334	(0.3264 ,	0.7315)
0.200	0.5820	(0.3533 ,	0.7854)
0.250	0.6228	(0.3739 ,	0.8282)
0.300	0.6583	(0.3908 ,	0.8628)
0.400	0.7188	(0.4183 ,	0.9138)
0.500	0.7701	(0.4414 ,	0.9480)
0.600	0.8157	(0.4628 ,	0.9707)
0.700	0.8579	(0.4843 ,	0.9854)
0.800	0.8982	(0.5081 ,	0.9942)
0.900	0.9394	(0.5393 ,	0.9987)
0.950	0.9625	(0.5638 ,	0.9997)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0019, 0.1367)	(0.0000, 0.0417)	(0.0291, 0.3231)

```
        (0.0163, 0.2701)          (0.0041, 0.1749)          (0.0518, 0.3859)
        (0.0466, 0.3735)          (0.0207, 0.2911)          (0.0937, 0.4623)
        (0.1183, 0.4963)          (0.0709, 0.4247)          (0.1847, 0.5681)
1                            R O C F I T  (JUNE 1993 VERSION) :

      M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
          O F   A   B I N O R M A L   R O C   C U R V E
                F R O M   R A T I N G   D A T A


        DATA DESCRIPTION: Reader 9, Benign or Malignant

        DATA COLLECTED IN  5 CATEGORIES
        WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

        NO. OF ACTUALLY NEGATIVE CASES =  125.     NO. OF ACTUALLY POSITIVE CASES =  125.


        RESPONSE DATA:
         CATEGORY                     1      2      3      4      5
         ACTUALLY NEGATIVE CASES     74.    45.     6.     0.     0.
         ACTUALLY POSITIVE CASES     14.    35.    54.    10.    12.


        OBSERVED OPERATING POINTS:
         FPF: 0.0000 0.0000 0.0000 0.0480 0.4080 1.0000
         TPF: 0.0000 0.0960 0.1760 0.6080 0.8880 1.0000

                 INITIAL VALUES OF PARAMETERS:
        A= 1.5928    B= 1.0021
        Z(K)=  0.2323     1.6649     2.5525     2.6525
        LOGL=  -291.5787
        CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES AR


        PROCEDURE CONVERGES AFTER   6 ITERATIONS.



                 FINAL VALUES OF PARAMETERS:
        A= 1.3650    B= 0.6517
        Z(K)=  0.2320     1.6703     3.5245     4.0979
        LOGL=  -276.9216
        CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES AR



                 VARIANCE-COVARIANCE MATRIX:
        A       0.0333   0.0153   0.0090   0.0013  -0.0356  -0.0483
        B       0.0153   0.0162   0.0030  -0.0129  -0.0612  -0.0759
        Z( 1)   0.0090   0.0030   0.0128   0.0060  -0.0025  -0.0052
        Z( 2)   0.0013  -0.0129   0.0060   0.0358   0.0715   0.0829
        Z( 3)  -0.0356  -0.0612  -0.0025   0.0715   0.2948   0.3453
        Z( 4)  -0.0483  -0.0759  -0.0052   0.0829   0.3453   0.4386



                 CORRELATION MATRIX:
        A       1.0000   0.6584   0.4356   0.0388  -0.3594  -0.4000
        B       0.6584   1.0000   0.2100  -0.5363  -0.8854  -0.9004
        Z( 1)   0.4356   0.2100   1.0000   0.2790  -0.0408  -0.0689
        Z( 2)   0.0388  -0.5363   0.2790   1.0000   0.6956   0.6613
        Z( 3)  -0.3594  -0.8854  -0.0408   0.6956   1.0000   0.9602
        Z( 4)  -0.4000  -0.9004  -0.0689   0.6613   0.9602   1.0000



            AREA =  0.8736      STD. DEV.(AREA) =  0.0249
1

        ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
        BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
        TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.3767	(0.2113 ,	0.5690)
0.010	0.4398	(0.2780 ,	0.6125)
0.020	0.5104	(0.3595 ,	0.6599)
0.030	0.5552	(0.4139 ,	0.6898)
0.040	0.5885	(0.4553 ,	0.7122)
0.050	0.6151	(0.4887 ,	0.7303)
0.060	0.6374	(0.5168 ,	0.7456)
0.070	0.6565	(0.5410 ,	0.7590)
0.080	0.6733	(0.5621 ,	0.7709)
0.090	0.6883	(0.5809 ,	0.7817)
0.100	0.7018	(0.5978 ,	0.7915)
0.110	0.7141	(0.6130 ,	0.8006)
0.120	0.7254	(0.6270 ,	0.8090)
0.130	0.7359	(0.6397 ,	0.8170)
0.140	0.7456	(0.6515 ,	0.8244)
0.150	0.7547	(0.6625 ,	0.8314)
0.200	0.7929	(0.7075 ,	0.8615)
0.250	0.8227	(0.7415 ,	0.8855)
0.300	0.8470	(0.7687 ,	0.9053)
0.400	0.8850	(0.8107 ,	0.9357)
0.500	0.9139	(0.8431 ,	0.9575)
0.600	0.9370	(0.8703 ,	0.9733)
0.700	0.9560	(0.8947 ,	0.9847)
0.800	0.9721	(0.9182 ,	0.9925)
0.900	0.9861	(0.9433 ,	0.9976)
0.950	0.9926	(0.9589 ,	0.9991)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0000, 0.0958)	(0.0000, 0.0157)	(0.0026, 0.3228)
(0.0002, 0.1756)	(0.0000, 0.0520)	(0.0069, 0.4058)
(0.0474, 0.6089)	(0.0206, 0.5138)	(0.0969, 0.6978)
(0.4083, 0.8876)	(0.3250, 0.8575)	(0.4959, 0.9128)

APPENDIX IV

B VIII

R O C F I T (JUNE 1993 VERSION) :

MAXIMUM   LIKELIHOOD   ESTIMATION
    OF   A   BINORMAL   ROC   CURVE
         FROM   RATING   DATA

DATA DESCRIPTION: Reader 10, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES =   42.

RESPONSE DATA:
  CATEGORY   1   2   3   4   5
  ACTUALLY NEGATIVE CASES   94.   4.   1.   0.   1.
  ACTUALLY POSITIVE CASES   14.   3.   3.   4.   18.

OBSERVED OPERATING POINTS:
  FPF: 0.0000 0.0100 0.0100 0.0200 0.0600 1.0000
  TPF: 0.0000 0.4286 0.5238 0.5952 0.6667 1.0000

         INITIAL VALUES OF PARAMETERS:
A= 1.5622   B= 0.6980
Z(K)= 1.5551   2.0542   2.2268   2.3268
LOGL= -87.2521
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER   5 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
A= 1.4407   B= 0.6401
Z(K)= 1.5592   1.9417   2.2197   2.5170
LOGL= -84.9281
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

         VARIANCE-COVARIANCE MATRIX:
A   0.3827   0.1857   0.0387 -0.0155 -0.0682 -0.1359
B   0.1857   0.1039   0.0084 -0.0248 -0.0567 -0.0972
Z(1)   0.0387   0.0084   0.0400   0.0346   0.0311   0.0273
Z(2) -0.0155 -0.0248   0.0346   0.0585   0.0639   0.0722
Z(3) -0.0682 -0.0567   0.0311   0.0639   0.0962   0.1157
Z(4) -0.1359 -0.0972   0.0273   0.0722   0.1157   0.1722

         CORRELATION MATRIX:
A   1.0000   0.9310   0.3127 -0.1038 -0.3552 -0.5292
B   0.9310   1.0000   0.1307 -0.3180 -0.5666 -0.7266
Z(1)   0.3127   0.1307   1.0000   0.7158   0.5011   0.3296
Z(2) -0.1038 -0.3180   0.7158   1.0000   0.8521   0.7189
Z(3) -0.3552 -0.5666   0.5011   0.8521   1.0000   0.8989
Z(4) -0.5292 -0.7266   0.3296   0.7189   0.8989   1.0000

     AREA = 0.8875   STD. DEV.(AREA) = 0.0691

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

113

```
    FPF       TPF        (LOWER BOUND, UPPER BOUND)

   0.005     0.4174      (   0.1907  ,    0.6767   )
   0.010     0.4806      (   0.2717  ,    0.6951   )
   0.020     0.5500      (   0.3638  ,    0.7256   )
   0.030     0.5935      (   0.4167  ,    0.7528   )
   0.040     0.6254      (   0.4508  ,    0.7773   )
   0.050     0.6508      (   0.4744  ,    0.7993   )
   0.060     0.6719      (   0.4916  ,    0.8190   )
   0.070     0.6900      (   0.5046  ,    0.8365   )
   0.080     0.7058      (   0.5148  ,    0.8520   )
   0.090     0.7198      (   0.5230  ,    0.8658   )
   0.100     0.7324      (   0.5297  ,    0.8782   )
   0.110     0.7439      (   0.5353  ,    0.8892   )
   0.120     0.7544      (   0.5402  ,    0.8990   )
   0.130     0.7641      (   0.5443  ,    0.9079   )
   0.140     0.7731      (   0.5480  ,    0.9159   )
   0.150     0.7815      (   0.5512  ,    0.9230   )
   0.200     0.8165      (   0.5630  ,    0.9501   )
   0.250     0.8435      (   0.5708  ,    0.9671   )
   0.300     0.8655      (   0.5765  ,    0.9782   )
   0.400     0.8995      (   0.5845  ,    0.9905   )
   0.500     0.9252      (   0.5902  ,    0.9960   )
   0.600     0.9455      (   0.5948  ,    0.9985   )
   0.700     0.9621      (   0.5989  ,    0.9995   )
   0.800     0.9761      (   0.6029  ,    0.9999   )
   0.900     0.9881      (   0.6074  ,    1.0000   )
   0.950     0.9937      (   0.6105  ,    1.0000   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND              UPPER BOUND
    ( FPF ,    TPF )             ( FPF ,    TPF )          ( FPF ,    TPF )

 (0.0059, 0.4323)               (0.0004, 0.2447)          (0.0442, 0.6369)
 (0.0132, 0.5079)               (0.0023, 0.3559)          (0.0535, 0.6587)
 (0.0261, 0.5784)               (0.0078, 0.4579)          (0.0711, 0.6919)
 (0.0595, 0.6710)               (0.0255, 0.5760)          (0.1215, 0.7560)
1                                R O C F I T  (JUNE 1993 VERSION) :
```

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
     O F   A   B I N O R M A L   R O C   C U R V E
          F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 10, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES =   51.

RESPONSE DATA:
```
 CATEGORY                        1      2      3      4      5
 ACTUALLY NEGATIVE CASES        91.     4.     0.     1.     4.
 ACTUALLY POSITIVE CASES        18.     4.     0.     5.    24.
```

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0400 0.0500 0.0900 1.0000

```
     TPF: 0.0000 0.4706 0.5686 0.6471 1.0000

          INITIAL VALUES OF PARAMETERS:
A=  1.7439    B=  1.0039
Z(K)=  1.3410     1.6452     1.7511
LOGL=   -99.3411
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


PROCEDURE CONVERGES AFTER   4 ITERATIONS.


          FINAL VALUES OF PARAMETERS:
A=  1.7844    B=  1.0437
Z(K)=  1.3425     1.5801     1.7761
LOGL=   -98.0825
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


          VARIANCE-COVARIANCE MATRIX:
A        0.6934   0.4292   0.0497 -0.0069 -0.0612
B        0.4292   0.2914   0.0129 -0.0273 -0.0655
Z( 1)    0.0497   0.0129   0.0311   0.0281   0.0258
Z( 2)   -0.0069  -0.0273   0.0281   0.0370   0.0395
Z( 3)   -0.0612  -0.0655   0.0258   0.0395   0.0529


          CORRELATION MATRIX:
A        1.0000   0.9547   0.3385 -0.0433 -0.3193
B        0.9547   1.0000   0.1350 -0.2628 -0.5272
Z( 1)    0.3385   0.1350   1.0000   0.8281   0.6350
Z( 2)   -0.0433  -0.2628   0.8281   1.0000   0.8929
Z( 3)   -0.3193  -0.5272   0.6350   0.8929   1.0000


     AREA =   0.8915      STD. DEV.(AREA) =   0.0515

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:


   FPF       TPF        (LOWER BOUND, UPPER BOUND)

   0.005     0.1829     (    0.0150   ,    0.6407   )
   0.010     0.2598     (    0.0475   ,    0.6488   )
   0.020     0.3596     (    0.1264   ,    0.6644   )
   0.030     0.4290     (    0.2035   ,    0.6813   )
   0.040     0.4828     (    0.2705   ,    0.7002   )
   0.050     0.5268     (    0.3258   ,    0.7211   )
   0.060     0.5641     (    0.3699   ,    0.7437   )
   0.070     0.5963     (    0.4045   ,    0.7672   )
   0.080     0.6246     (    0.4313   ,    0.7906   )
   0.090     0.6498     (    0.4521   ,    0.8133   )
   0.100     0.6725     (    0.4684   ,    0.8346   )
   0.110     0.6929     (    0.4813   ,    0.8543   )
   0.120     0.7116     (    0.4917   ,    0.8722   )
   0.130     0.7287     (    0.5002   ,    0.8882   )
   0.140     0.7444     (    0.5072   ,    0.9025   )
   0.150     0.7589     (    0.5131   ,    0.9151   )
   0.200     0.8176     (    0.5321   ,    0.9584   )
   0.250     0.8601     (    0.5423   ,    0.9801   )
   0.300     0.8921     (    0.5487   ,    0.9907   )
   0.400     0.9358     (    0.5563   ,    0.9981   )
   0.500     0.9628     (    0.5605   ,    0.9997   )
```

1

```
      0.600     0.9797      (    0.5632  ,   1.0000   )
      0.700     0.9901      (    0.5650  ,   1.0000   )
      0.800     0.9961      (    0.5661  ,   1.0000   )
      0.900     0.9991      (    0.5665  ,   1.0000   )
      0.950     0.9998      (    0.5663  ,   1.0000   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

```
EXPECTED OPERATING POINT          LOWER BOUND            UPPER BOUND
    ( FPF ,    TPF )            ( FPF ,    TPF )        ( FPF ,    TPF )

  (0.0379, 0.4724)            (0.0130, 0.2946)        (0.0926, 0.6559)
  (0.0570, 0.5538)            (0.0252, 0.3981)        (0.1145, 0.7016)
  (0.0897, 0.6492)            (0.0457, 0.5090)        (0.1594, 0.7716)
1                                R O C F I T (JUNE 1993 VERSION) :
```

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
   O F   A   B I N O R M A L   R O C   C U R V E
      F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 10, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES =   23.

RESPONSE DATA:
 CATEGORY   1   2   3   4   5
 ACTUALLY NEGATIVE CASES   96.   2.   1.   1.   0.
 ACTUALLY POSITIVE CASES   20.   2.   0.   0.   1.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0000 0.0100 0.0200 0.0400 1.0000
 TPF: 0.0000 0.0435 0.0435 0.0435 0.1304 1.0000

           INITIAL VALUES OF PARAMETERS:
A= 0.0057   B= 0.6871
Z(K)= 1.7511   2.0542   2.3268   2.5762
LOGL=   -34.0185
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   7 ITERATIONS.

           FINAL VALUES OF PARAMETERS:
A= 0.1095   B= 0.7126
Z(K)= 1.7463   2.1891   2.3811   2.7516
LOGL=   -33.5911
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

           VARIANCE-COVARIANCE MATRIX:
A   1.2379 0.5909 0.0566 -0.0612 -0.1250 -0.2807
B   0.5909 0.3157 0.0114 -0.0532 -0.0884 -0.1745
Z(1)   0.0566 0.0114 0.0514 0.0437 0.0408 0.0356
Z(2) -0.0612 -0.0532 0.0437 0.0968 0.0986 0.1071
```

```
          Z( 3) -0.1250 -0.0884  0.0408  0.0986  0.1412  0.1559
          Z( 4) -0.2807 -0.1745  0.0356  0.1071  0.1559  0.3118


             CORRELATION MATRIX:
          A        1.0000  0.9453  0.2243 -0.1767 -0.2989 -0.4518
          B        0.9453  1.0000  0.0898 -0.3045 -0.4188 -0.5560
          Z( 1)    0.2243  0.0898  1.0000  0.6202  0.4794  0.2813
          Z( 2)   -0.1767 -0.3045  0.6202  1.0000  0.8436  0.6162
          Z( 3)   -0.2989 -0.4188  0.4794  0.8436  1.0000  0.7429
          Z( 4)   -0.4518 -0.5560  0.2813  0.6162  0.7429  1.0000
```

         AREA =   0.5355   STD. DEV.(AREA) =   0.3512
1
   ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
   BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
   TRUE-POSITIVE FRACTION AT EACH SPECIFIED
   FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.0421	(0.0027 ,	0.2502)
0.010	0.0607	(0.0078 ,	0.2487)
0.020	0.0878	(0.0181 ,	0.2692)
0.030	0.1091	(0.0260 ,	0.3017)
0.040	0.1275	(0.0313 ,	0.3392)
0.050	0.1439	(0.0346 ,	0.3787)
0.060	0.1590	(0.0366 ,	0.4182)
0.070	0.1730	(0.0378 ,	0.4570)
0.080	0.1862	(0.0384 ,	0.4942)
0.090	0.1987	(0.0386 ,	0.5298)
0.100	0.2107	(0.0386 ,	0.5634)
0.110	0.2222	(0.0384 ,	0.5951)
0.120	0.2333	(0.0380 ,	0.6249)
0.130	0.2441	(0.0376 ,	0.6528)
0.140	0.2545	(0.0371 ,	0.6789)
0.150	0.2646	(0.0366 ,	0.7033)
0.200	0.3120	(0.0337 ,	0.8021)
0.250	0.3553	(0.0308 ,	0.8703)
0.300	0.3959	(0.0281 ,	0.9165)
0.400	0.4718	(0.0233 ,	0.9678)
0.500	0.5436	(0.0192 ,	0.9890)
0.600	0.6140	(0.0155 ,	0.9969)
0.700	0.6854	(0.0122 ,	0.9993)
0.800	0.7609	(0.0091 ,	0.9999)
0.900	0.8468	(0.0058 ,	1.0000)
0.950	0.9001	(0.0040 ,	1.0000)

   ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
   CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
   CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0030, 0.0321)	(0.0001, 0.0043)	(0.0487, 0.1420)
(0.0086, 0.0562)	(0.0009, 0.0173)	(0.0500, 0.1440)
(0.0143, 0.0735)	(0.0026, 0.0297)	(0.0571, 0.1548)
(0.0404, 0.1282)	(0.0142, 0.0733)	(0.0965, 0.2066)

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
O F   A   B I N O R M A L   R O C   C U R V E
F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 10, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES = 100.

RESPONSE DATA:
CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	91.	6.	2.	1.	0.
ACTUALLY POSITIVE CASES	37.	22.	20.	6.	15.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0000 0.0100 0.0300 0.0900 1.0000
 TPF: 0.0000 0.1500 0.2100 0.4100 0.6300 1.0000

        INITIAL VALUES OF PARAMETERS:
A= 1.8597   B= 1.1295
Z(K)= 1.3410   1.8812   2.3268   2.5762
LOGL= −186.6256
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

        FINAL VALUES OF PARAMETERS:
A= 1.6595   B= 0.9936
Z(K)= 1.3387   1.8972   2.4656   2.7230
LOGL= −186.2753
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

        VARIANCE−COVARIANCE MATRIX:
A	0.3016	0.1713	0.0444	−0.0289	−0.1175	−0.1599
B	0.1713	0.1138	0.0102	−0.0408	−0.1014	−0.1302
Z(1)	0.0444	0.0102	0.0310	0.0251	0.0193	0.0167
Z(2)	−0.0289	−0.0408	0.0251	0.0514	0.0715	0.0813
Z(3)	−0.1175	−0.1014	0.0193	0.0715	0.1364	0.1605
Z(4)	−0.1599	−0.1302	0.0167	0.0813	0.1605	0.2006

        CORRELATION MATRIX:
A	1.0000	0.9249	0.4596	−0.2320	−0.5793	−0.6499
B	0.9249	1.0000	0.1723	−0.5331	−0.8142	−0.8616
Z(1)	0.4596	0.1723	1.0000	0.6282	0.2976	0.2124
Z(2)	−0.2320	−0.5331	0.6282	1.0000	0.8537	0.8011
Z(3)	−0.5793	−0.8142	0.2976	0.8537	1.0000	0.9706
Z(4)	−0.6499	−0.8616	0.2124	0.8011	0.9706	1.0000

     AREA = 0.8804   STD. DEV.(AREA) = 0.0438

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE−POSITIVE FRACTION AT EACH SPECIFIED
FALSE−POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.1840	(0.0429 ,	0.4670)
0.010	0.2571	(0.0914 ,	0.5109)
0.020	0.3514	(0.1766 ,	0.5656)
0.030	0.4169	(0.2456 ,	0.6060)
0.040	0.4680	(0.3013 ,	0.6405)
0.050	0.5099	(0.3465 ,	0.6716)
0.060	0.5455	(0.3835 ,	0.7002)
0.070	0.5765	(0.4141 ,	0.7266)
0.080	0.6038	(0.4398 ,	0.7511)
0.090	0.6282	(0.4616 ,	0.7736)
0.100	0.6502	(0.4803 ,	0.7943)
0.110	0.6703	(0.4967 ,	0.8132)
0.120	0.6886	(0.5111 ,	0.8305)
0.130	0.7055	(0.5240 ,	0.8462)
0.140	0.7211	(0.5356 ,	0.8605)
0.150	0.7356	(0.5462 ,	0.8736)
0.200	0.7949	(0.5882 ,	0.9228)
0.250	0.8388	(0.6195 ,	0.9530)
0.300	0.8726	(0.6448 ,	0.9717)
0.400	0.9205	(0.6859 ,	0.9902)
0.500	0.9515	(0.7201 ,	0.9969)
0.600	0.9720	(0.7511 ,	0.9992)
0.700	0.9854	(0.7815 ,	0.9998)
0.800	0.9937	(0.8134 ,	1.0000)
0.900	0.9983	(0.8520 ,	1.0000)
0.950	0.9995	(0.8792 ,	1.0000)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0032, 0.1477)	(0.0002, 0.0275)	(0.0325, 0.4310)
(0.0068, 0.2146)	(0.0007, 0.0656)	(0.0408, 0.4716)
(0.0289, 0.4108)	(0.0096, 0.2524)	(0.0731, 0.5855)
(0.0903, 0.6291)	(0.0461, 0.4947)	(0.1602, 0.7492)

APPENDIX IV

B IX

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
O F   A   B I N O R M A L   R O C   C U R V E
F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 11, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES =   42.

RESPONSE DATA:

CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	76.	17.	0.	1.	6.
ACTUALLY POSITIVE CASES	13.	1.	0.	2.	26.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0600 0.0700 0.2400 1.0000
 TPF: 0.0000 0.6190 0.6667 0.6905 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.6234   B= 0.1714
Z(K)= 0.7060   1.4761   1.5551
LOGL= -113.0300
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.6617   B= 0.2222
Z(K)= 0.7099   1.4142   1.5978
LOGL= -111.9829
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

A	0.0626	0.0207	0.0054	-0.0002	-0.0026
B	0.0207	0.0174	0.0017	-0.0046	-0.0074
Z(1)	0.0054	0.0017	0.0189	0.0132	0.0121
Z(2)	-0.0002	-0.0046	0.0132	0.0329	0.0316
Z(3)	-0.0026	-0.0074	0.0121	0.0316	0.0415

CORRELATION MATRIX:

A	1.0000	0.6284	0.1570	-0.0048	-0.0516
B	0.6284	1.0000	0.0938	-0.1911	-0.2756
Z(1)	0.1570	0.0938	1.0000	0.5295	0.4318
Z(2)	-0.0048	-0.1911	0.5295	1.0000	0.8557
Z(3)	-0.0516	-0.2756	0.4318	0.8557	1.0000

AREA = 0.7408   STD. DEV.(AREA) = 0.0756

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF   TPF   (LOWER BOUND, UPPER BOUND)

```
0.005    0.5356    (    0.3324  ,    0.7297    )
0.010    0.5575    (    0.3684  ,    0.7342    )
0.020    0.5813    (    0.4066  ,    0.7411    )
0.030    0.5963    (    0.4297  ,    0.7468    )
0.040    0.6074    (    0.4462  ,    0.7519    )
0.050    0.6164    (    0.4590  ,    0.7565    )
0.060    0.6240    (    0.4694  ,    0.7608    )
0.070    0.6307    (    0.4782  ,    0.7649    )
0.080    0.6366    (    0.4856  ,    0.7688    )
0.090    0.6420    (    0.4921  ,    0.7725    )
0.100    0.6469    (    0.4979  ,    0.7761    )
0.110    0.6514    (    0.5030  ,    0.7796    )
0.120    0.6556    (    0.5076  ,    0.7829    )
0.130    0.6596    (    0.5117  ,    0.7862    )
0.140    0.6633    (    0.5155  ,    0.7894    )
0.150    0.6669    (    0.5190  ,    0.7925    )
0.200    0.6825    (    0.5329  ,    0.8070    )
0.250    0.6956    (    0.5428  ,    0.8203    )
0.300    0.7072    (    0.5503  ,    0.8325    )
0.400    0.7276    (    0.5609  ,    0.8549    )
0.500    0.7459    (    0.5679  ,    0.8754    )
0.600    0.7636    (    0.5729  ,    0.8947    )
0.700    0.7817    (    0.5765  ,    0.9136    )
0.800    0.8020    (    0.5789  ,    0.9329    )
0.900    0.8280    (    0.5800  ,    0.9546    )
0.950    0.8478    (    0.5795  ,    0.9681    )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0550, 0.6204)	(0.0229, 0.5862)	(0.1154, 0.6537)
(0.0786, 0.6359)	(0.0384, 0.6058)	(0.1448, 0.6651)
(0.2389, 0.6928)	(0.1637, 0.6715)	(0.3298, 0.7136)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
        F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 11, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES =   51.

RESPONSE DATA:

CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	95.	0.	0.	1.	4.
ACTUALLY POSITIVE CASES	26.	2.	0.	0.	23.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0400 0.0500 0.0500 1.0000
 TPF: 0.0000 0.4510 0.4510 0.4902 1.0000

        INITIAL VALUES OF PARAMETERS:

```
A=  1.5769    B=  0.9713
Z(K)=  1.5452    1.6452    1.7511
LOGL=   -67.9594
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


PROCEDURE CONVERGES AFTER   5 ITERATIONS.


        FINAL VALUES OF PARAMETERS:
A=  1.6025    B=  0.9900
Z(K)=  1.6444    1.7102    1.7441
LOGL=   -66.6294
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE


        VARIANCE-COVARIANCE MATRIX:
A       4.1910   2.4630   0.0735  -0.0363  -0.0944
B       2.4630   1.4733   0.0178  -0.0482  -0.0832
Z( 1)   0.0735   0.0178   0.0446   0.0434   0.0428
Z( 2)  -0.0363  -0.0482   0.0434   0.0474   0.0483
Z( 3)  -0.0944  -0.0832   0.0428   0.0483   0.0512


        CORRELATION MATRIX:
A       1.0000   0.9912   0.1699  -0.0814  -0.2037
B       0.9912   1.0000   0.0695  -0.1825  -0.3028
Z( 1)   0.1699   0.0695   1.0000   0.9449   0.8960
Z( 2)  -0.0814  -0.1825   0.9449   1.0000   0.9806
Z( 3)  -0.2037  -0.3028   0.8960   0.9806   1.0000


        AREA =   0.8726      STD. DEV.(AREA) =   0.1617
1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:


    FPF       TPF       (LOWER BOUND, UPPER BOUND)

   0.005    0.1716    (   0.0008  ,   0.8977   )
   0.010    0.2416    (   0.0095  ,   0.8277   )
   0.020    0.3332    (   0.0688  ,   0.7331   )
   0.030    0.3975    (   0.1615  ,   0.6802   )
   0.040    0.4478    (   0.2436  ,   0.6673   )
   0.050    0.4895    (   0.2873  ,   0.6945   )
   0.060    0.5251    (   0.2958  ,   0.7461   )
   0.070    0.5561    (   0.2860  ,   0.8016   )
   0.080    0.5836    (   0.2690  ,   0.8504   )
   0.090    0.6083    (   0.2500  ,   0.8896   )
   0.100    0.6306    (   0.2310  ,   0.9197   )
   0.110    0.6510    (   0.2128  ,   0.9421   )
   0.120    0.6697    (   0.1959  ,   0.9586   )
   0.130    0.6870    (   0.1802  ,   0.9706   )
   0.140    0.7030    (   0.1658  ,   0.9792   )
   0.150    0.7178    (   0.1525  ,   0.9853   )
   0.200    0.7792    (   0.1010  ,   0.9976   )
   0.250    0.8251    (   0.0672  ,   0.9996   )
   0.300    0.8608    (   0.0448  ,   0.9999   )
   0.400    0.9118    (   0.0195  ,   1.0000   )
   0.500    0.9455    (   0.0080  ,   1.0000   )
   0.600    0.9681    (   0.0029  ,   1.0000   )
   0.700    0.9831    (   0.0009  ,   1.0000   )
   0.800    0.9926    (   0.0002  ,   1.0000   )
```

```
    0.900      0.9980        (    0.0000  ,    1.0000    )
    0.950      0.9994        (    0.0000  ,    1.0000    )




        ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
        CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
        CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:


EXPECTED OPERATING POINT          LOWER BOUND          UPPER BOUND
     ( FPF ,    TPF )             ( FPF ,    TPF )      ( FPF ,    TPF )

    (0.0406, 0.4506)             (0.0143, 0.2866)     (0.0967, 0.6236)
    (0.0436, 0.4639)             (0.0163, 0.3040)     (0.0996, 0.6299)
    (0.0500, 0.4898)             (0.0198, 0.3316)     (0.1093, 0.6497)
1                                R O C F I T (JUNE 1993 VERSION) :

    M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
        O F   A   B I N O R M A L   R O C   C U R V E
            F R O M   R A T I N G   D A T A


    DATA DESCRIPTION: Reader 11, FAS/AD

    DATA COLLECTED IN  5 CATEGORIES
    WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

    NO. OF ACTUALLY NEGATIVE CASES =  100.    NO. OF ACTUALLY POSITIVE CASES =   23.

    RESPONSE DATA:
      CATEGORY                   1      2      3      4      5
      ACTUALLY NEGATIVE CASES   73.    1.     0.    14.    12.
      ACTUALLY POSITIVE CASES   13.    1.     0.     5.     4.

    OBSERVED OPERATING POINTS:
     FPF: 0.0000 0.1200 0.2600 0.2700 1.0000
     TPF: 0.0000 0.1739 0.3913 0.4348 1.0000

            INITIAL VALUES OF PARAMETERS:
    A=  0.6094     B=  1.3192
    Z(K)=  0.6125     0.6430     1.1751
    LOGL=  -106.1220
    CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


    PROCEDURE CONVERGES AFTER   3 ITERATIONS.


            FINAL VALUES OF PARAMETERS:
    A=  0.6843     B=  1.3990
    Z(K)=  0.6117     0.6559     1.1707
    LOGL=  -105.9773
    CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


            VARIANCE-COVARIANCE MATRIX:
    A        0.3212   0.2899   0.0325   0.0300  -0.0014
    B        0.2899   0.3677   0.0120   0.0086  -0.0324
    Z( 1)    0.0325   0.0120   0.0180   0.0176   0.0132
    Z( 2)    0.0300   0.0086   0.0176   0.0181   0.0140
    Z( 3)   -0.0014  -0.0324   0.0132   0.0140   0.0263
```

```
          CORRELATION MATRIX:
A        1.0000   0.8435   0.4273   0.3936  -0.0149
B        0.8435   1.0000   0.1470   0.1056  -0.3302
Z( 1)    0.4273   0.1470   1.0000   0.9726   0.6091
Z( 2)    0.3936   0.1056   0.9726   1.0000   0.6421
Z( 3)   -0.0149  -0.3302   0.6091   0.6421   1.0000


        AREA =   0.6547        STD. DEV.(AREA) =   0.0889
```

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.0018	(0.0000 ,	0.2380)
0.010	0.0051	(0.0000 ,	0.2586)
0.020	0.0143	(0.0001 ,	0.2840)
0.030	0.0257	(0.0004 ,	0.3022)
0.040	0.0387	(0.0011 ,	0.3174)
0.050	0.0529	(0.0026 ,	0.3310)
0.060	0.0679	(0.0049 ,	0.3438)
0.070	0.0837	(0.0084 ,	0.3561)
0.080	0.1000	(0.0130 ,	0.3683)
0.090	0.1167	(0.0188 ,	0.3804)
0.100	0.1337	(0.0259 ,	0.3927)
0.110	0.1511	(0.0341 ,	0.4053)
0.120	0.1686	(0.0434 ,	0.4182)
0.130	0.1863	(0.0536 ,	0.4316)
0.140	0.2041	(0.0646 ,	0.4456)
0.150	0.2219	(0.0762 ,	0.4601)
0.200	0.3110	(0.1372 ,	0.5426)
0.250	0.3979	(0.1919 ,	0.6380)
0.300	0.4805	(0.2348 ,	0.7342)
0.400	0.6295	(0.2939 ,	0.8855)
0.500	0.7531	(0.3348 ,	0.9637)
0.600	0.8504	(0.3685 ,	0.9921)
0.700	0.9218	(0.4003 ,	0.9990)
0.800	0.9687	(0.4343 ,	0.9999)
0.900	0.9934	(0.4784 ,	1.0000)
0.950	0.9986	(0.5130 ,	1.0000)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.1209, 0.1702)	(0.0683, 0.0811)	(0.1968, 0.3053)
(0.2559, 0.4078)	(0.1789, 0.2735)	(0.3475, 0.5540)
(0.2704, 0.4319)	(0.1908, 0.2948)	(0.3637, 0.5779)

1   R O C F I T (JUNE 1993 VERSION) :

M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
    O F   A   B I N O R M A L   R O C   C U R V E
        F R O M   R A T I N G   D A T A

DATA DESCRIPTION: Reader 11, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT'

NO. OF ACTUALLY NEGATIVE CASES = 100.   NO. OF ACTUALLY POSITIVE CASES = 100.

RESPONSE DATA:
CATEGORY	1	2	3	4	5
ACTUALLY NEGATIVE CASES	56.	31.	13.	0.	0.
ACTUALLY POSITIVE CASES	21.	38.	18.	14.	9.

OBSERVED OPERATING POINTS:
 FPF: 0.0000 0.0000 0.0000 0.1300 0.4400 1.0000
 TPF: 0.0000 0.0900 0.2300 0.4100 0.7900 1.0000

          INITIAL VALUES OF PARAMETERS:
A= 0.8157   B= 0.7526
Z(K)= 0.1507   1.1265   2.4762   2.5762
LOGL= −270.4485
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER   7 ITERATIONS.

          FINAL VALUES OF PARAMETERS:
A= 0.8626   B= 0.7836
Z(K)= 0.1283   1.2717   2.1074   2.8588
LOGL= −249.0090
CHI−SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

          VARIANCE−COVARIANCE MATRIX:
A	0.0316	0.0134	0.0127	0.0070	−0.0015	−0.0119
B	0.0134	0.0174	0.0044	−0.0078	−0.0229	−0.0396
Z(1)	0.0127	0.0044	0.0157	0.0086	0.0045	0.0006
Z(2)	0.0070	−0.0078	0.0086	0.0247	0.0289	0.0356
Z(3)	−0.0015	−0.0229	0.0045	0.0289	0.0647	0.0826
Z(4)	−0.0119	−0.0396	0.0006	0.0356	0.0826	0.1506

          CORRELATION MATRIX:
A	1.0000	0.5699	0.5690	0.2500	−0.0329	−0.1725
B	0.5699	1.0000	0.2638	−0.3768	−0.6815	−0.7725
Z(1)	0.5690	0.2638	1.0000	0.4374	0.1427	0.0120
Z(2)	0.2500	−0.3768	0.4374	1.0000	0.7221	0.5829
Z(3)	−0.0329	−0.6815	0.1427	0.7221	1.0000	0.8373
Z(4)	−0.1725	−0.7725	0.0120	0.5829	0.8373	1.0000

     AREA = 0.7514   STD. DEV.(AREA) = 0.0382

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE−POSITIVE FRACTION AT EACH SPECIFIED
FALSE−POSITIVE FRACTION:

FPF	TPF	(LOWER BOUND,	UPPER BOUND)
0.005	0.1238	(0.0441 ,	0.2718)
0.010	0.1684	(0.0728 ,	0.3207)
0.020	0.2275	(0.1178 ,	0.3791)
0.030	0.2704	(0.1544 ,	0.4187)

0.040	0.3052	(	0.1860	,	0.4497	)
0.050	0.3349	(	0.2142	,	0.4756	)
0.060	0.3609	(	0.2397	,	0.4982	)
0.070	0.3844	(	0.2631	,	0.5183	)
0.080	0.4057	(	0.2847	,	0.5366	)
0.090	0.4254	(	0.3048	,	0.5534	)
0.100	0.4436	(	0.3237	,	0.5690	)
0.110	0.4607	(	0.3415	,	0.5837	)
0.120	0.4768	(	0.3582	,	0.5975	)
0.130	0.4920	(	0.3741	,	0.6106	)
0.140	0.5064	(	0.3892	,	0.6230	)
0.150	0.5201	(	0.4036	,	0.6350	)
0.200	0.5805	(	0.4667	,	0.6880	)
0.250	0.6309	(	0.5188	,	0.7329	)
0.300	0.6744	(	0.5632	,	0.7719	)
0.400	0.7468	(	0.6364	,	0.8364	)
0.500	0.8058	(	0.6965	,	0.8870	)
0.600	0.8556	(	0.7491	,	0.9265	)
0.700	0.8985	(	0.7977	,	0.9566	)
0.800	0.9360	(	0.8454	,	0.9787	)
0.900	0.9690	(	0.8970	,	0.9932	)
0.950	0.9843	(	0.9286	,	0.9977	)

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

EXPECTED OPERATING POINT (FPF , TPF)	LOWER BOUND (FPF , TPF)	UPPER BOUND (FPF , TPF)
(0.0021, 0.0842)	(0.0001, 0.0242)	(0.0179, 0.2172)
(0.0175, 0.2151)	(0.0046, 0.1191)	(0.0538, 0.3453)
(0.1017, 0.4468)	(0.0571, 0.3537)	(0.1676, 0.5428)
(0.4490, 0.7770)	(0.3543, 0.7155)	(0.5467, 0.8301)

APPENDIX

5 A

The University of Virginia PACS

Fontaine Research Center

(1) 2K Diagnostic Workstation (Orthopaedics Clinic)

Stacey Hall

5 Miles

(1) 2K Diagnostic Workstation (MR Clinic)

Republic Plaza

0.2 Miles

(1) 2K Diagnostic Workstation (Neurosurgical Visualization Laboratory)

MR-4 Building

0.5 Miles

(1) 2K Diagnostic Workstation (Research & Development)

Lumisys 150 Digitizer

Single Mode Repeater

FDDI Hub

Siemens MR
Merge
Gateway

2 Gbyte File Server

FDDI Hub

4 Gbyte File Server

FDDI Hub

Sun-based Archive Host — AMASS
330GB DISC Archive (Compressed)

Print Spooler
3M 969 Laser Camera

System Admin W/S
35mm Slide Maker

5 Miles

Single Mode Repeater

University Hospital West

5 Miles

GE 9800 CT | Uroskop™
Merge | Merge
Gateway | Gateway

FDDI Hub

(5) 2K Diagnostic Workstations (Cancer Center, Neuro Clinic)

(1) 1K Clinical Workstation (Urology)

University Hospital

0.2 Miles

8 Gbyte File Server
4 Gbyte File Server
2 Gbyte File Server

(5) 2K Diagnostic Workstations (Radiology, Reading Rooms, Neuro ICU)

(1) 1K Teleradiology Receive Station

0.1 Miles

FDDI Hub

Gateway | Gateway | Gateway | Gateway
| Merge | | Merge
Gateway | Picker CT | Picker CT | Siemens MR | GE 9800 CT
Picker CT

Remote Sites via 19.2k

AS9504-78

Third Party Interfaces

An E-Systems Company

APPENDIX

5 B

DISPLAY SYSTEM

Display Workstation

Host Computer

131
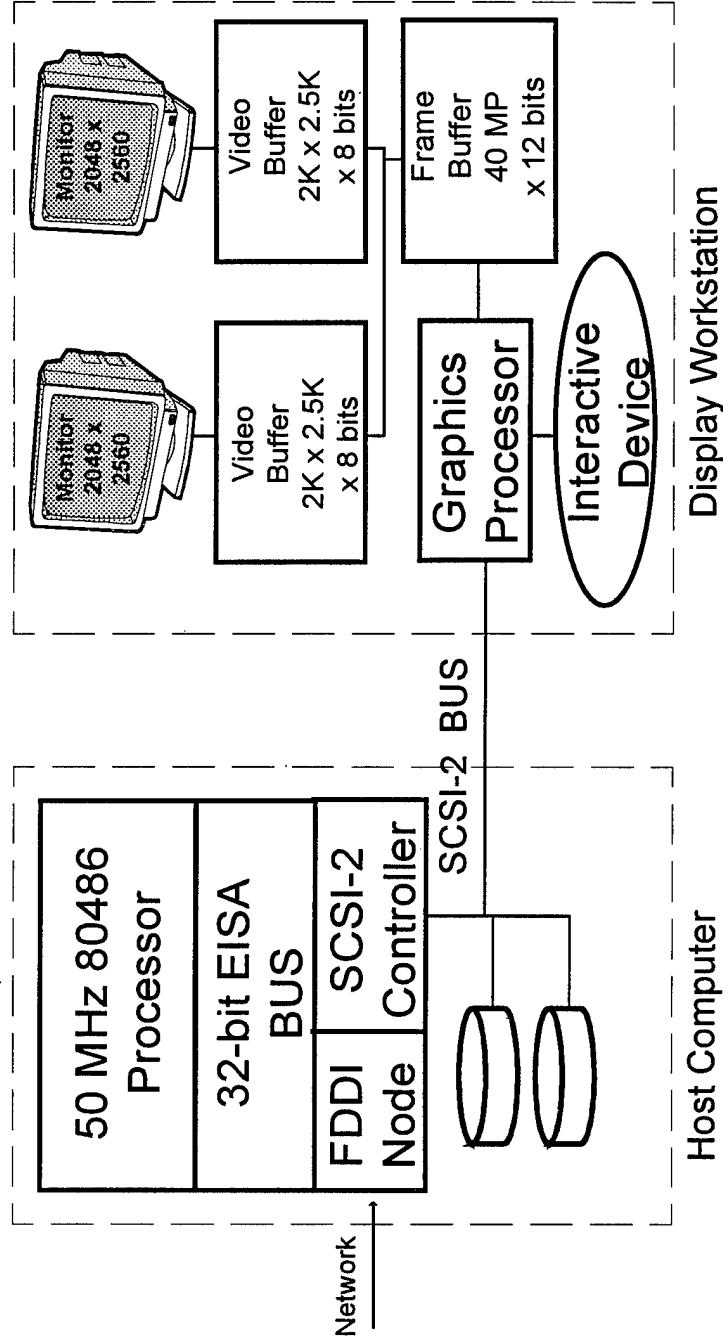
APPENDIX

5 C

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

Brent K. Stewart, Ph.D.
Associate Professor and Director
Diagnostic Physics Laboratory
Department of Radiology, RC-05

NW040J Health Sciences Bldg.
206.548.6252 (office)
206.543.3495 (fax)
bstewart@u.washington.edu

19 March 1995

Samuel J. Dwyer III, Ph.D.
Professor
Department of Radiology
University of Virginia
MR-4 Room 1190
Charlottesville, VA 22908

Dear Sam:

Please find enclosed the findings of my visit to the Medical College of Virginia on 1/27/95 and the University of Virginia on 1/28/95 as consultant on the US Army Medical Research and Development Command grant entitled: "Evaluation of a Digital Telemammography System: a Model for a Regional System."

Visit to the Medical College of Virginia

On 1/27/95, I met with Ellen Shaw de Parades, M.D., Chief of Mammography at the Medical College of Virginia's Department of Radiology and Principal Investigator of the telemammography grant. The purpose of the consulting at the Medical College of Virginia was to analyze the design of the Receiver Operator Characteristics (ROC) studies, comment on the method of selecting images for the study, examine the images already collected for the study, and discuss strategies for analysis of the ROC after the testing has concluded. I prepared a list of questions (given below). I also sat through a few of the tests to give advice on reading room environment, e.g., view box luminance and glare.

<u>I submitted a list of questions to Dr. de Parades regarding the analog film and digital softcopy ROC testing</u>:
1. Has the ROC testing commenced and if so, how far along is it?
2. Has the ROC study design changed significantly from that stated in the initial proposal?
3. How are the mammograms for the ROC study selected?
4. You are selecting age-matched normal controls. Are you matching these normal mammograms for overall parenchymal density as well? If so, how are you accomplishing this?
5. Are the initial 200 mammograms cited in the grant application digitized yet? If so, what is keeping you from initiating the digital softcopy ROC portion of the study?

6. For mammogram digitization, what quality control/assurance program have you instituted?

7. In the original grant application, it was stated that the digital softcopy review might occur on any of ten different 2K resolution workstations throughout the UVA Department of Radiology. Unless these workstation's monitors are periodically and effectively calibrated, this might confound the ROC results.

8. In the original grant application, the images read at the remote Northridge outpatient clinic were to be subjected to a preference test (scale: 1-5). Would it be better to have these cases overread by mammographers at UVA and statistically calculate the analysis of variance?

9. Reading all of the analog images first produces a bias in the ROC test. It would be better to have one-half of the radiologists read the digital softcopy images first and the other radiologists read the analog images first. Of course, as there will be multiple reading sessions for each modality, each session could be randomly picked from analog or digital. This bias may, of course, be confounded as the radiologists will know which images are analog and which are digital.

10. Is ground truth available for all of the films to be used in the study? What aside information are you using to establish ground truth? Is there a truth committee? If so, who is on it and how do they arrive a conclusion regarding a case without unanimity?

11. A random number generator should also be used for ordering the analog and digital normals and abnormals in each of the ROC study sessions. Is this the case and if not, why not?

12. Who will be collecting, collating and performing the analysis of the ROC test result data? Will you be using one of the standard software packages like ROCFIT or CORROC from the University of Chicago?

13. In the grant, it is stated that in addition to the 50μm digitized radiographs, that some would be digitized at 23μm. If so, how many and are you adding this as another section of the original ROC study?

14. It appears from the grant application that the ROC results will be pooled for the four different pathology types. Is this still the case? Will you achieve sufficient statistical power in the non-pooled case?

15. How has splitting the grant across institutions (UVA and MCV) affected the design and execution of the proposed work?

16. Will you be using the BIRADS system information for patient selection? It doesn't appear that the RadCare radiology information system in place at the MCV will facilitate on-line image selection for the ROC. What system will you have to help automate patient selection?

17. Are there any problems in selecting cases from both MCV and UVA in terms of image quality differences? There should be differences in film type, screen type, mammography machine output, film processing, etc.

18. It will be possible to time the readers using the computer in the softcopy display workstation. Are you planning on doing this? If so, could the radiologist write-down the start and end times on the scoring sheets?

<u>Advice on ROC Reading Sessions:</u>
I also sat through three sessions of analog ROC testing with one private practice mammographer and two MCV faculty radiologists. A specific mammography view panel was used, This viewing panel had the capability of shuttering out extraneous light around the edges of the films, however, this was not done in all cases by all radiologists. Both 8"x10" and 10"x12" films were used. One row was used at a time. The medio-lateral views paired on the left, the cranial-caudal radiographs were paired on the right. The room, the mammography reading room, was fairly quiet, but was simultaneously used by another radiologist and a resident, as well as Dr. de Parades during the ROC sessions. The readers did interrupt their reading sessions to speak with colleagues or answer the phone/pager. There were no overhead lights to contend with and there was no light reflections on the ROC viewbox.

A magnifying lens was provided (will an analogous "zooming" capability be added to the softcopy display workstation as well?). A hot lamp was available (will an analogous grayscale look-up table facility be added to the softcopy display workstation as well?).

The reading sessions consist of 50 patient studies, each consisting of four radiographs (2 CC/2MLO). There is one three ring binder notebook for each reader. All of the instructions for each reader are in the notebooks, as well as all of the reader responses for each patient case read.

On the average, the magnifying glass was used in 96% of the cases read, whereas, the hot lamp was used only sparingly, about 10% of the time. The radiologists always started with the MLO views and then the CC views. Any zooming and panning would need to happen quickly to be effective (not slowing down the reading process significantly. There were several instances of the radiologists being interrupted for pages and consultations. If a timer were to be integrated into the softcopy reading workstation, a pause button would be useful.

There were several instances where films were displaced vertically to come into registration (vertical shift). This capability may need to be added to the digital review workstation. It would be very hard to be the video monitors close enough for bi-lateral comparison. Digital panning may be necessary. On the average it took two minutes and 18 seconds to read one of the 50 studies in the ROC study list.

<div align="center">Visit to the University of Virginia</div>

On 1/28/95, I met with Samuel J. Dwyer, Ph.D., Director of PACS and Co-Prinicpal Investigator of the telemammography grant at the Medical College of Virginia's Department of Radiology. I also met with Beth Elias, B.S., the systems analyst for the telemammography grant. The purpose of the consulting at the University of Virginia was to examine and provide recommendations for mammogram digitization, image presentation on the viewing monitors, and image processing functionality.

I made several recommendations regarding image digitization quality control, specifically daily digitization of a standard test pattern and periodic cleaning and calibration of the digitizer. I also suggested several means of displaying the image digitally to the radiologists for that portion of the ROC testing. There were also questions regarding where an additional image reading station for the MCV portion of the digital ROC testing were coming from. It might be the case the E-systems will loan as system to the MCV for the duration of the ROC testing. Due to construction and a snow storm, it was not convenient to visit the Northridge site.

Image Digitization:
The images are being digitized at the UVA under the direction of Ms. Elias. A Lumisys digitizer, model 150, is being used for the digitization. A SMPTE (Society of Motion Picture Test Engineers) is being used for daily grayscale and resolution quality control. The mirrors of the system are cleaned bi-monthly. Every four months, a field engineer from E-systems recalibrated the digitizer densitometry.

It was suggested that the name of the patient, the patient identification number, the date of the examination and the name of the institution be masked off with electrical tape prior to digitization. It was also suggested that a single normal mammogram be used for daily grayscale quality control. This mammogram could be digitized every day, prior to digitization of mammograms for the digital part of the study. Once registered spatially, the daily mammogram could be digitally subtracted from the baseline one and the difference image studied. If it appeared that there is more than simple noise differences in the difference image, e.g., structure evident, then the densitometry might need to be adjusted more often than every four months.

Image Presentation on the Viewing Monitors:
How many monitors are going to be used for the workstations in the study? Only two. It was observed above that the radiologists reviewing the analog cases switched back and forth between the CC and MLO pairs quite often. If only two video monitors were used, this would severely hamper both the comparison necessary for diagnosis, but significantly increase the interpretation time as well. Methods were discussed with Ms. Elias for quickly context switching between the two sets (MLO and CC) of mammograms for each patient. The limiting factor here is that it is only possible to load two mammograms into the E-systems MegaScan 2K monitor digital frame buffer (32 Mbyte limit). Having to re-paint the frame buffers from magnetic disk for each MLO <-> CC context switch will most likely be interminably slow.

It was also suggested that a sequential worklist of patients for the softcopy review workstation portion of the ROC study be instituted. Currently, the radiologist has to select images from a pull-down menu list with small font. The easiest thing for the radiologists to have to do would be to push a "hot key" to advance to the next patient in the ROC study list automatically. Otherwise, with the limitations of the MLO <-> CC context switching and having to search through a complicated list of code numbers, the radiologists will become frustrated, which might impact the results of that portion of the ROC test.

<u>Image Processing</u>:
In order to emulate the functionality of the hot lamp and the magnifying glass, image processing functions will be implemented on the digital viewing station. However, the zooming functionality included with the E-systems MegaScan monitors looks overly complicated for a function that the radiologists used about 96% of the time in the analog portions of the ROC tests.

With regards to grayscale modifications of the digital mammograms, the user can change both the brightness and the contrast. This is accomplished fairly easily using the mouse, moving it either up or down for contrast modification and left to right for brightness/darkness changes. However, as there are three buttons on the optical mouse, a specific series of button pushes are necessary to invoke and dismiss the grayscale look-up table modification software. The radiologists are going to have to have something simple to get through the set of 50 image cases in a reasonable amount of time. I can foresee a great amount of frustration with the current user interface for zooming and look-up table modification. All but one of the mouse buttons should be disabled for the ROC testing.

Please let me know if there is anything else that you may require in this matter. It has been a pleasure working with you and Dr. de Parades on the telemammography project.

Sincerely,

Brent K. Stewart, Ph.D.
Consultant to the US Army Medical Research and Development Command Grant
Evaluation of a Digital Telemammography System: a Model for a Regional System